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Edited for the Council by J. LAURENCE PRITCHARD, Fellow.

All communications should be addressed to the Editor.

No. 138. JUNE, 1922. VOL. XXVI.

Notices of the Royal Aëronautical Society.

Election of Members.

The following members were elected at a Council meeting held on Tuesday, May 16th:—

Student.—W. K. Mackenzie.

Associate Members.—H. V. Bullbrook, E. C. Gaccon, F. W. Gaccon, P. Hoggins, P. E. Williams.

SCOTTISH BRANCH: *Associate Member.*—James Hamilton.

Wilbur Wright Lecture.

The Annual Wilbur Wright Lecture will be delivered at 5.30 p.m., on Thursday, June 15th, in the Theatre of the Royal Society of Arts, John Street, Adelphi, when Lieut.-Colonel A. Ogilvie, C.B.E., F.R.Aë.S., will read a paper on "Some Aspects of Aeronautical Research."

Research.

The Council are again considering the question of the continued reduction in expenditure on research by the Air Ministry. The views of the Council on this matter, as laid before the Secretary of State for Air at an interview on January 17th last, will be found in a previous number of the Journal (Vol. XXVI., at page 43).

Committees.

The following is the full list of Committees appointed for the year ending April, 1923:—

Candidates' Committee.—Prof. L. Bairstow, Prof. B. Melvill Jones, Wing Commander T. R. Cave-Browne-Cave, Squadron Leader R. M. Hill, Prof. C. F. Jenkin, Mr. W. O. Manning, Dr. N. A. V. Piercy, Dr. A. J. Sutton Pippard.

Finance Committee.—Mr. Griffith Brewer, Lieut.-Col. A. Ogilvie, Mr. A. E. Turner (Hon. Treas.), Mr. F. P. Walsh.

Publications and Library Committee.—Prof. L. Bairstow, Major F. M. Green, Squadron Leader R. M. Hill, Major A. R. Low, Mr. J. D. North, Lieut.-Col. H. W. S. Outram, Dr. A. J. Sutton Pippard, Mr. J. L. Pritchard (Editor) and Major R. V. Southwell.

The Chairman (Lieut.-Colonel M. O'Gorman) and Vice-Chairman (Air-Commodore H. R. M. Brooke-Popham) are *ex-officio* members of all the Society's committees.

XIIM

Representatives.

The following members have been nominated by the Council to represent the Society on other bodies for the year ending April, 1923:—

Air League of the British Empire.—Lieut.-Col. M. O'Gorman, Rear-Admiral M. F. Sueter, and the Secretary.

Joint Standing Committee with the Society of British Aircraft Constructors.—Prof. L. Bairstow, Wing Commander T. R. Cave-Browne-Cave, Lieut.-Colonel A. Ogilvie, Major-General Sir R. M. Ruck.

Conjoint Board of Scientific Societies.—Lieut.-Colonel M. O'Gorman.

Aeronautical Research Committee.—Lieut.-Colonel A. Ogilvie.

Advisory Committee on Aeronautical Education.—Prof. C. F. Jenkin.

British Engineering Standards Association. Aircraft Committee.—Lieut.-Colonel M. O'Gorman. *Nomenclature Sub-Committee.*—Prof. L. Bairstow, Mr. J. D. North, Lieut.-Col. M. O'Gorman, Dr. A. J. Sutton Pippard, Major R. V. Southwell, and the Secretary.

Civil Aviation Advisory Board.—Lieut.-Col. M. O'Gorman.

International Air Congress, 1923.—Mr. Griffith Brewer, Lieut.-Colonel A. Ogilvie, Lieut.-Colonel M. O'Gorman, Lieut.-Colonel W. Lockwood Marsh (Technical Secretary).

Students' Section.

The date of the students' visit to the National Physical Laboratory has been changed from Saturday, June 3rd, to Saturday, June 10th. Students desiring to attend are reminded that they should meet at 9.15 a.m. for special tickets at the Booking Office, Waterloo Station (L.S.W.R.).

Binding Cases for the Journal.

The arrangements made for the binding of complete sets of the Journal in blue cloth cases with gilt lettering at a charge of 4s. 6d. per volume, including the supply of the case, are still in force. Members who desire to take advantage of this arrangement should forward their sets direct to the Lewes Press, Ltd., High Street, Lewes, at the same time sending a remittance for 4s. 6d. to the Secretary at the Society's offices. A note stating the name and address of the sender should be included in the parcel to the binders. The complete volume will be returned direct to members postage paid.

W. Lockwood Marsh, *Secretary.*

CORRECTION.

In Major Barlow's paper, page 153, paragraph 3, the law of densities should read:—

$$\rho_H/\rho_{II} = P_H/P_{II}.$$

PROCEEDINGS.

NINTH MEETING, 57th SESSION.

A meeting of the Society was held at the rooms of the Royal Society of Arts, John Street, Adelphi, London, on Thursday, March 2nd, 1922, the Chairman, Lieut.-Colonel M. O'Gorman, in the chair.

The CHAIRMAN, introducing Mr. William D. Douglas, A.R.C.Sc.I., A.F.R.Ae.S., and in calling upon him to read his paper on "Testing Aircraft to Destruction," said he had done much to develop methods of testing aircraft, both to destruction and also for their eventual survival.

TESTING AIRCRAFT TO DESTRUCTION.

WM. D. DOUGLAS, A.R.C.Sc.I., A.F.R.Ae.S.

SYNOPSIS.

1. Introductory.

Necessity for strength tests to supplement calculations and to check the assumptions on which the calculations are based. Historical outline. Examples of certain types of defect which are revealed by strength test.

2. Description of Present Methods.

Assumed aerodynamic conditions. Approximations reproduced by test loading. Methods of support during test. Measurements, testing routine and technique.

The usual tests are described:—Flight test, C.P. forward; Flight test, C.P. back; Nose dive test; Tests of auxiliary and controlling surfaces; Ailerons, elevators and rudder; Tailplane and fins; Fuselage, down load, side load, torsion; Undercarriage, discussion of stresses which may arise during landing, pointing out presence of frictional horizontal force causing rotational acceleration of the wheels; Static tests of undercarriages, dropping tests; General description of rib tests.

3. Conclusion.

Description of shot bags and general principles of load application with a view to efficiency and safety.

Introductory.

In many branches of engineering fatal results may follow simple errors, but nowhere is this so evidently true as in aeronautics. The aeroplane designer, however well equipped with technical knowledge and armed with the recorded experience of the aircraft world, cannot afford to neglect any opportunity of detecting the occasional mistakes which he is liable to make, and of rectifying the same before they reveal themselves in the air.

Efficient inspection, checking of calculations, etc., serve to eliminate the majority of the dangerous defects in design and material, but there are certain forms of weakness which are not evident under simple inspection or which may owe their origin to faulty assumptions and which may therefore escape detection if the assumptions are common to the designer and the checker

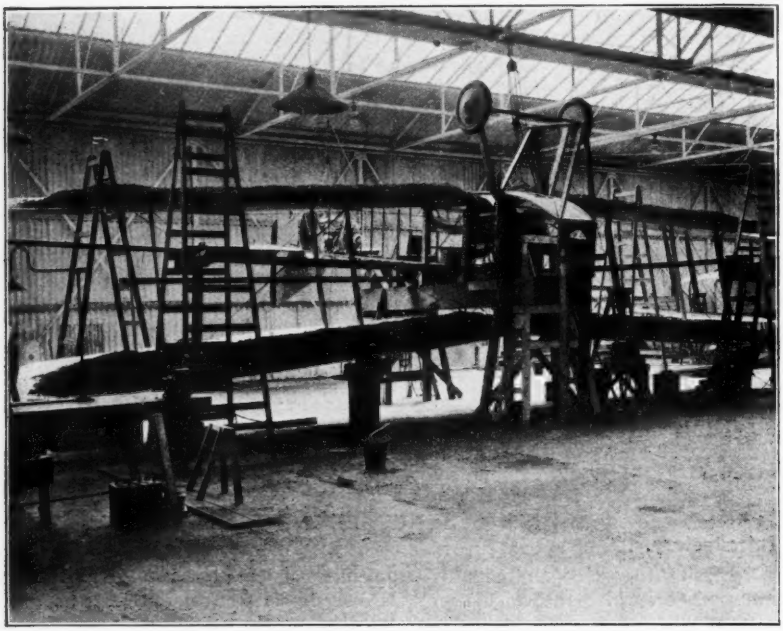


FIG. 3.—*Sand as a loading material.*

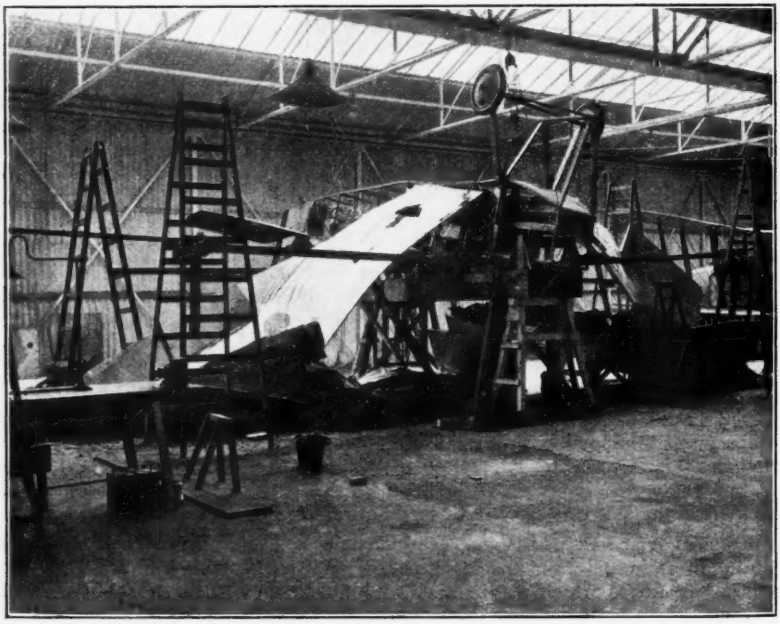


FIG. 4.—*Result of allowing complete collapse.*

Even in the early days of aircraft construction, designs were occasionally submitted to simple forms of strength test. Fig. 1,* which appeared in "The Aero" of August 3, 1910, illustrates one of the first recorded tests of this nature, where M. Levavasseur, the designer of the famous Antoinette monoplanes, is conducting a static loading test on a port plane. To prove his confidence in the correctness of his calculations he is photographed while seated under the loaded structure. This heroic method of proof is not recommended, although certainly it would tend to eliminate bad designers. Fig. 2* shows the plane after collapse. It is of interest to notice that the load consists of wood planks, which could not be expected to produce the correct bending in the spars as the pile of planks would in itself resist bending, and the greater part of their weight would be transferred to the points of support of the plane.

In succeeding years, a gradual improvement in methods of test may be traced. Various materials were used for loading purposes, including bricks (either loose or packed in boxes), gravel and sand.

Fig. 3 illustrates the type of main plane test at Farnborough, 1914 to 1916. Loose sand was mainly used, and no precautions were taken to prevent the complete collapse (Fig. 4) of the structure, with the result that it was difficult with certainty to determine the location of primary failure.

The use of sand, which is an entirely unsuitable loading material, whether loose or in bags, was soon discontinued, and for the last six years loading has been done by means of suitably designed, and accurately weighed, shot bags or by lever systems. In any case where it is necessary to use a granular loading material on small surfaces, loose shot is employed, as it possesses the following advantages over sand.

(*a*) "Arching" effect is less evident.
(*b*) Weight is not dependent on moisture content.
(*c*) Maximum loading gradient is two and one-half times greater than dry sand.
(*d*) Bulk is much less.

The obsolete term "sand test" is of course misleading, and its occasional use as recently as 1918 gave rise to many misconceptions.

Typical Failures during Test.

Before outlining the methods at present employed for testing aeroplane structures it will be of interest to examine some typical failures which are obtained from time to time. The following have been selected for their illustrative value, and since some of the actual parts photographed failed at loads considerably in excess of those for which they were designed, they should not be taken individually to indicate weakness of any particular type of machine or errors on the part of any particular designer.

For permission to use the information and accompanying illustrations in this Paper, I am indebted to the Air Ministry and to the Superintendent of the Royal Aircraft Establishment, Farnborough.

Fig. 5 shows a lateral failure of the spars where the front and rear spars have buckled forwards in the inner bay in the plane of the chord.

If the plane had been covered with new fabric during the test, this type of failure would have been prevented. If the spars are weak in the plane of the chord, a satisfactory test could be made by having slack or weathered fabric in place. Since it is difficult to obtain a particular plane with fabric of a suitable degree of slackness, tests are usually made with the fabric entirely removed.

* Not printed.—EDITOR.

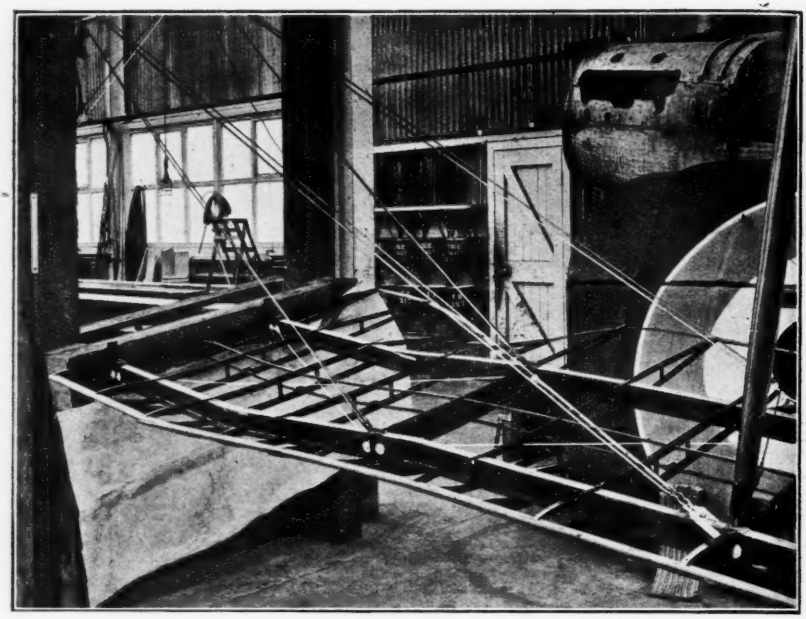


FIG. 5.—*Lateral failure of spars.*

Fig. 6 shows a very common case where the yielding of timber under a steel fitting and in front of a bolt has allowed such distortion that the forces brought into play cause failure of one of the parts at a load less than that for which the fitting has been designed.

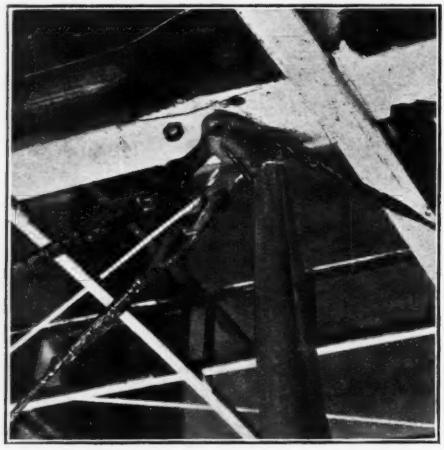


FIG. 6.—*Movement of bolt in timber.*

In this particular case it will be seen that one of the ordinary bolts after shearing through the spar for about half an inch has failed. The pull of the

lift cables has tilted the fitting and the end of the strut has fractured above the socket.

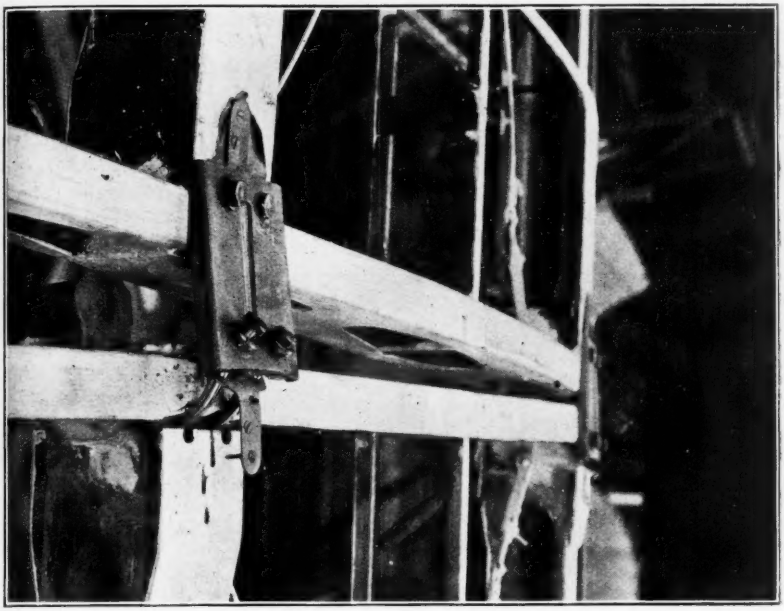


FIG. 7.—*Bolt failure at centre section.*

Fig. 7 shows a somewhat similar type of failure where the bolts attaching a top main plane to the centre section have sheared through the wood of the spar and finally failed in the threaded portion.

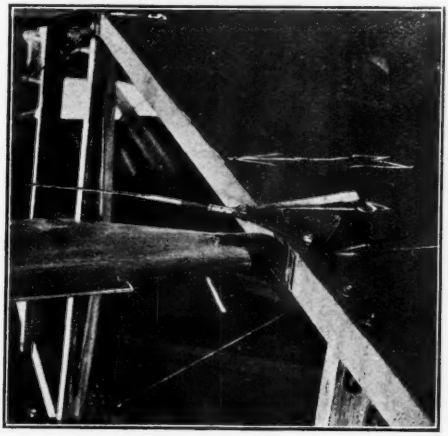


FIG. 8.—*Excessive bearing pressure under fitting.*

Observation of the preliminary phases of the distortion of bolts in timber is possible with X-rays, and the use of a comparatively simple set would be of advantage in many instances.

Fig. 8 shows an example of a simple bracket (under a centre section strut) which allowed too great a bearing pressure on the timber of the fuselage longitudinal on which it was mounted. The crushing of the timber might have resulted in local weakness of the longitudinal, but having been revealed by the test, it was of course easily prevented in other machines of the type.

In ailerons, elevators and similar control members it is sometimes convenient to mount control levers or their bracing attachments at the side of, or offset from, one of the ribs. The calculation of the stresses due to such mounting is complex, and in such cases designers usually trust to their general sense of proportion guided by previous experience. Fig. 9 illustrates a case where failure has occurred

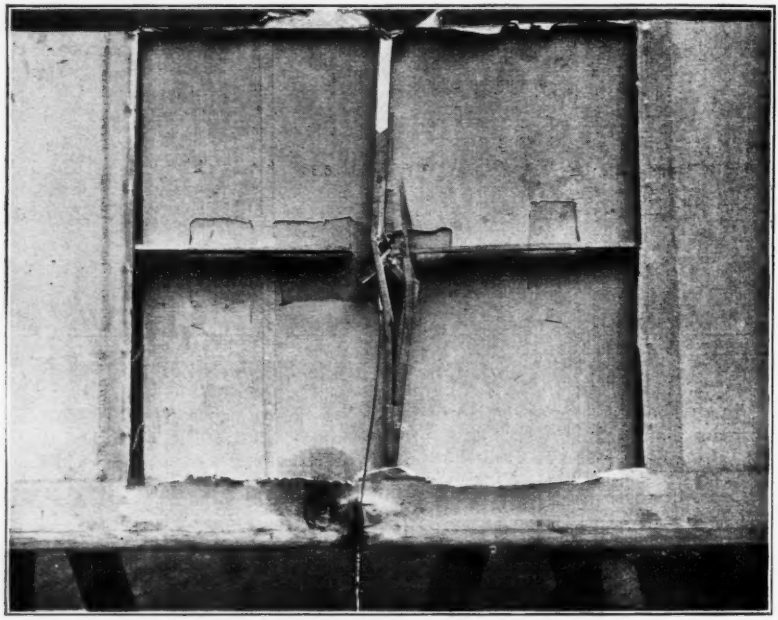


FIG. 9.—*Offset bracing attachment.*

in such an offset attachment for the bracing wire of a control lever. The same remarks apply to control pulleys, often mounted on cantilever fittings, which may deflect or even tear away long before the ultimate strength of the remaining parts of the control has been reached. Fig. 10 and Fig. 11 may serve as examples.

Down load or side load on a fuselage usually produces a failure of the tension bracing or of the longitudinals. In the latter case either one or both of the longitudinals which are in compression fail as continuous struts. Fig. 12 shows a case of this nature.

It will be seen that the bottom longitudinals have buckled outwards in one bay and inwards in the adjacent bay. This fuselage was tested without fabric covering, since the bracing effect of the latter is a variable and somewhat doubtful factor.

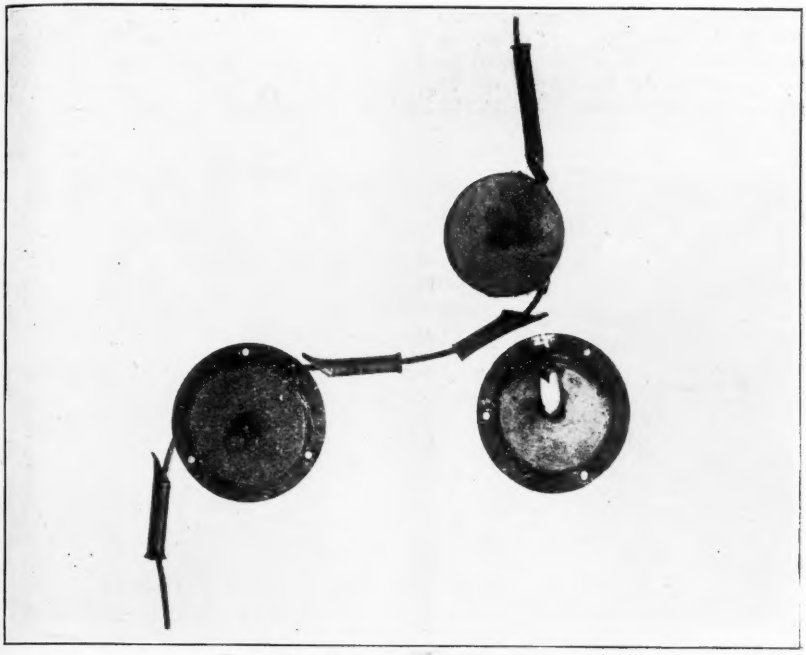


FIG. 10.—*Failure of pulley fitting.*

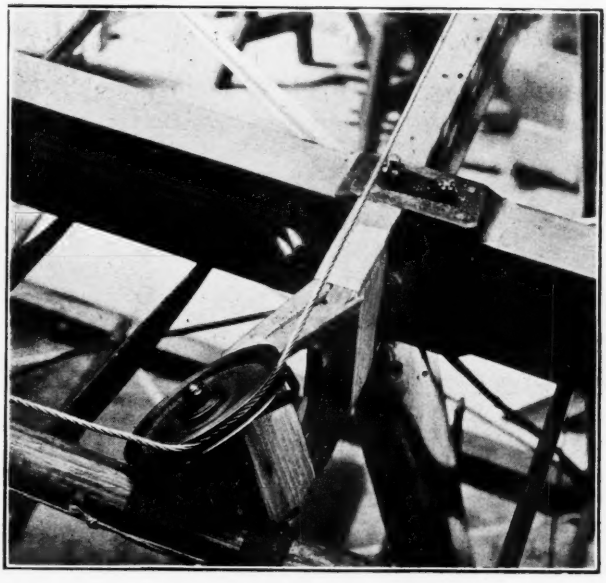


FIG. 11.—*Failure of pulley mounting.*

Occasionally the fuselage joint fittings distort or fracture. An example of the latter is shown in Fig. 13, where the pull of the bracing wire on the left-hand side of the illustration has caused fracture of the light alloy casting which acts as a socket for the fuselage strut. This illustration also shows the stretch of the bracing due to the terminal loop closing, the ferrule slipping along the wire.

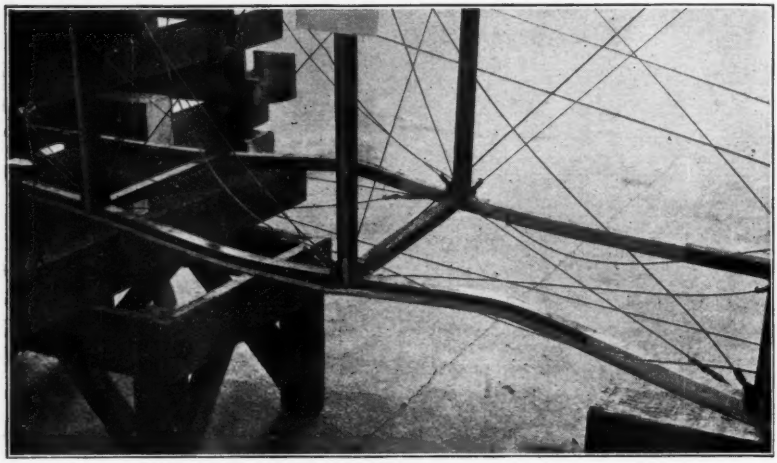


FIG. 12.—*Failure of longitudinals.*

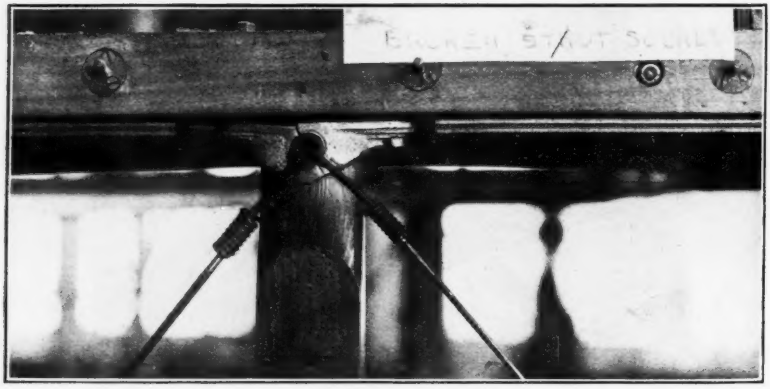


FIG. 13.—*Failure of fuselage fitting.*

Fig. 14 illustrates the "V" strut of an undercarriage which has buckled at A and subsequently distorted on the opposite side of the axle.

A somewhat similar example is shown in Fig. 15, where the front strut of a "V" undercarriage has buckled inwards and forwards. The fairing and the rubber shock absorber were removed after test for photographic purposes.

Present Methods of Testing Structures.

The following description gives only a brief outline of the main tests which are frequently applied to the structure of conventional types of medium and small size machines. The limits of the present Paper do not permit any reference to special tests which are called for as occasion demands nor to the extension of testing methods to large or unusual types of aeroplanes. Tests of spars, fittings, materials, etc., are also omitted.

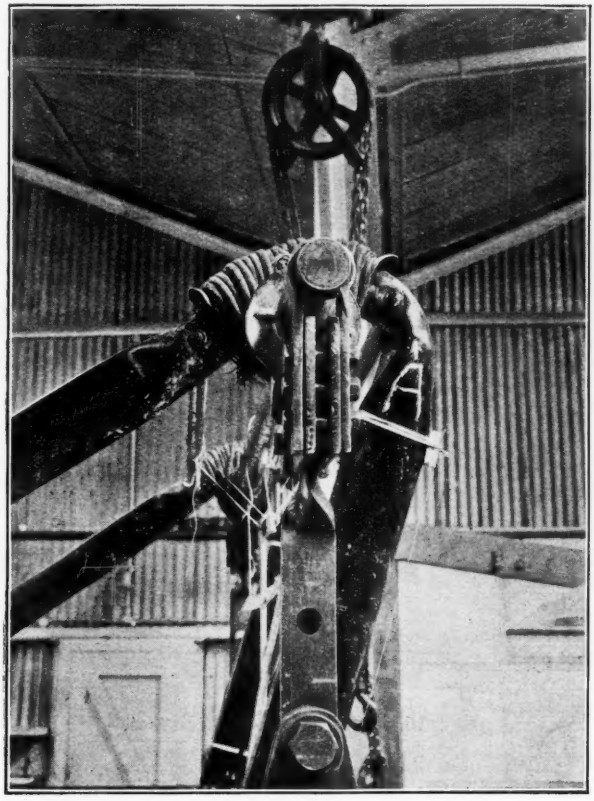


FIG. 14.—*Buckled undercarriage strut.*

In the formulation of any test the following procedure is usually adopted :—

(*a*) The particular conditions to be represented are ascertained.

(*b*) The airloading under these conditions is obtained or assumptions founded on the best aerodynamical data available are made.

(*c*) In many cases it is necessary to assume some modification of the above airloading to suit the limitations of the test loading process.

(*d*) Arrangements are made for the gravitational or other acceleration forces, which balance the air force, to be represented by controlled reactions supplemented, if necessary, by other applied forces.

Consider a typical case. For any given speed the maximum lift force which can act on the main plane of a machine will occur when the planes are at their stalling incidence. This condition might occur when pulling out of a dive, and the speed at the instant might, therefore, have a high value.

Complete information as to the distribution of lift and drag forces and of pitching moments is not available for all wing sections, but where the section in question bears a general resemblance to the standard sections for which data exist, no great error is likely to result from intelligent interpolation.

The distribution of the air forces having been decided, or assumed, it will be found that the resultants of the lift and drag forces on the various cross-sections of the planes do not all act in exactly the same direction. Since gravita-

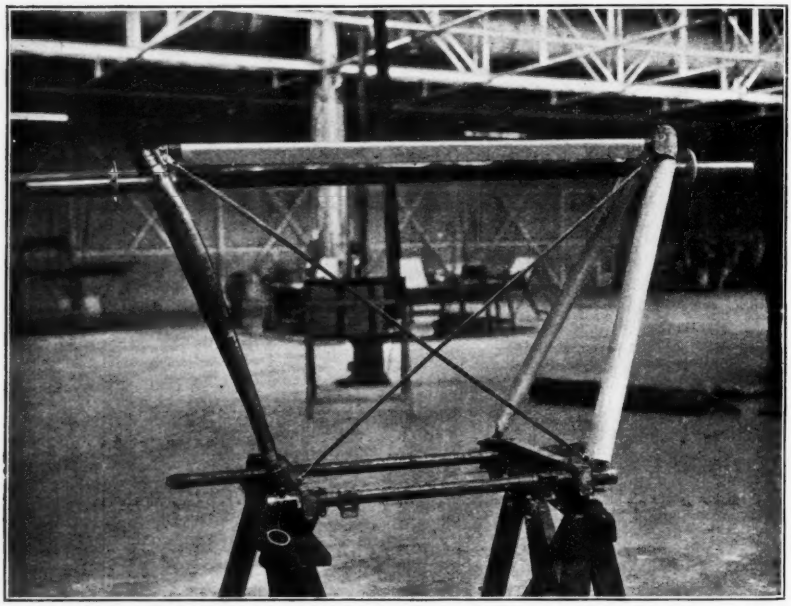


FIG. 15.—*Undercarriage after test.*

tional force is to be utilised to represent the resultant air force, it will only be possible to reproduce a distribution of forces in which the lift and drag components at the various cross-sections bear a fixed ratio and have therefore a uniform direction for their resultants. This direction must, of course, coincide with the direction of the resultant air force on the whole main plane system. These approximations and assumptions are familiar to all, as they form the usual basis of design calculations.

Except where there are definite reasons against so doing, it is usual to assume that the drag component is everywhere 1/7th of the lift, that the centre of pressure coefficient is the same for every cross-section of the plane and that the grading of the loading along the span is uniform to within a definite distance from the tip.

The attitude of the machine during test will necessarily be fixed, since the resultant air force on the planes is to be represented by gravity. The diagram in

Fig. 16 illustrates the case where the stalling angle of the plane is 16deg. Fig. 17 illustrates the same machine inverted and mounted for test, the attitude of the machine being arranged so that the relative direction of the resultant air force is vertical. The latter may, therefore, be represented by gravitational force.

For strength calculation purposes, the attachments of the main plane structure to the fuselage are usually treated as fixed relatively. This approximate assumption is unavoidable on account of the extreme complication of the structural calculations when the deflection and distortion of the various members in the central part of the fuselage are taken into account. Fortunately, this limitation

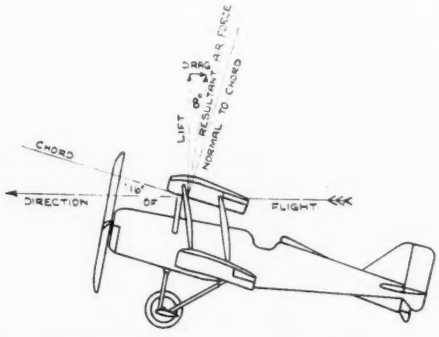


FIG. 16 CONVENTIONAL LIFT & DRAG FORCES ON AEROPLANE AT STALLING INCIDENCE.

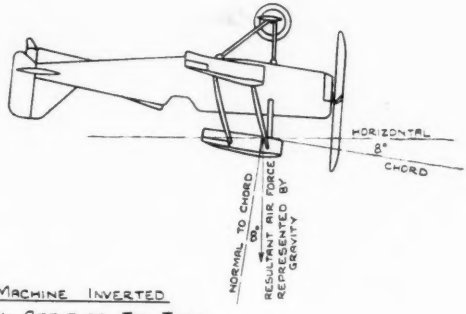


FIG. 17. MACHINE INVERTED IN ATTITUDE FOR TEST

is less evident in testing, and it is possible to arrange for the main plane attachments to deflect relatively under load in a manner similar to that which might be expected to take place in the air. This may be effected by arranging that the reactions of the fuselage supports will represent the mean acceleration forces which act on the fuselage and its attachments.

Approximation is again necessary, since it is evidently impracticable to support each member of the fuselage and its contents separately. A suitable compromise may be made by selecting four to six points of support corresponding with the main weights such as engine unit, tanks, crew, undercarriage, etc. (see Fig. 18). When the machine has been erected for test, supports may be placed at the points selected as above, using a simple system of levers to ensure that the

reactions have the desired relative values. Each support may be arranged so that its reaction passes through the centre of gravity of the particular mass concerned. The ratio of the reaction forces will not be made identical with the ratio of the isolated masses, but will be modified so that the resultant reaction will pass through the centre of gravity of the whole machine.

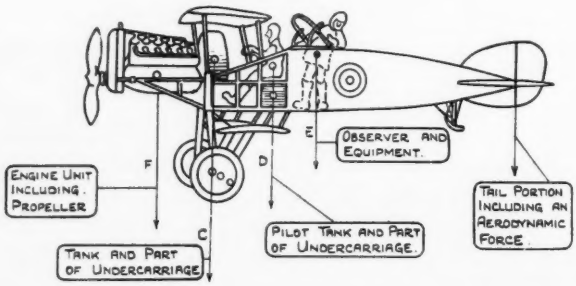


FIG. 18. DISPOSITION OF CHIEF MASSES IN TYPICAL MILITARY FUSELAGE.

SUITABLE PROPORTIONS OF THE MASS OF THE FUSELAGE STRUCTURE MAY BE INCLUDED WITH THE VARIOUS ITEMS INDICATED ABOVE.

For equilibrium, a further force will be necessary; this may be supplied by securing the tailplane at, say, the hinges of the elevators. The reaction, thus automatically brought into play when the planes are loaded, will represent roughly the aerodynamic load on the tailplane under the flight conditions which have been assumed.

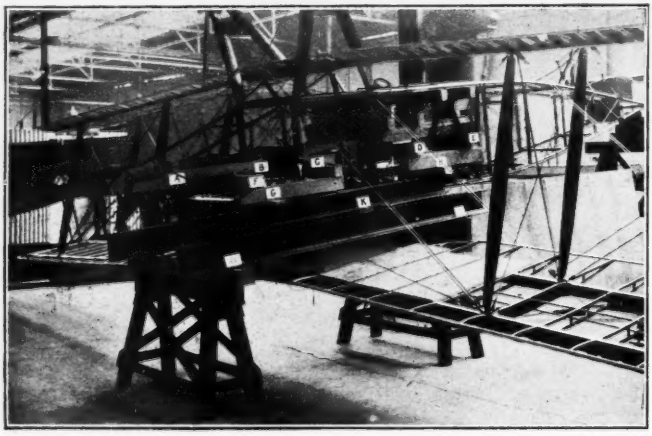


FIG. 19.—*Arrangement of supports for main plane test.*

Fig. 19 shows a Bristol machine mounted in course of preparation for test. Supports at "A" and "B" represent the engine unit, and the reactions act on the engine mounting. The lever "AB" rests on a cross bar "F" placed under the position of the centre of gravity of the engine unit. A support at "C" fitted to the tank mounting represents the acceleration force on the main tank and part

of the undercarriage. The reaction from the support " D " is distributed on the seat bearers to represent the pilot, the tank over which he sits, and remaining portions of the undercarriage. Support at " E " represents the observer and his military or other equipment. By means of wooden beams and levers pivoted at " G " and " H " and a short steel lever pivoted at " K," the reactions on the supporting points are distributed as desired. The point " K " and a corresponding point for the other side of the fuselage are arranged in the plane containing the centre of gravity of the aeroplane.

To prevent the machine rocking, the tail is supported and secured to a heavy trestle.

In some special cases the mounting of the fuselage is a matter of considerable difficulty, since adequate provision must be made to ensure safety during various possible types of collapse. Fig. 20 illustrates such a special case, showing a Supermarine A.D. Boat erected for test.

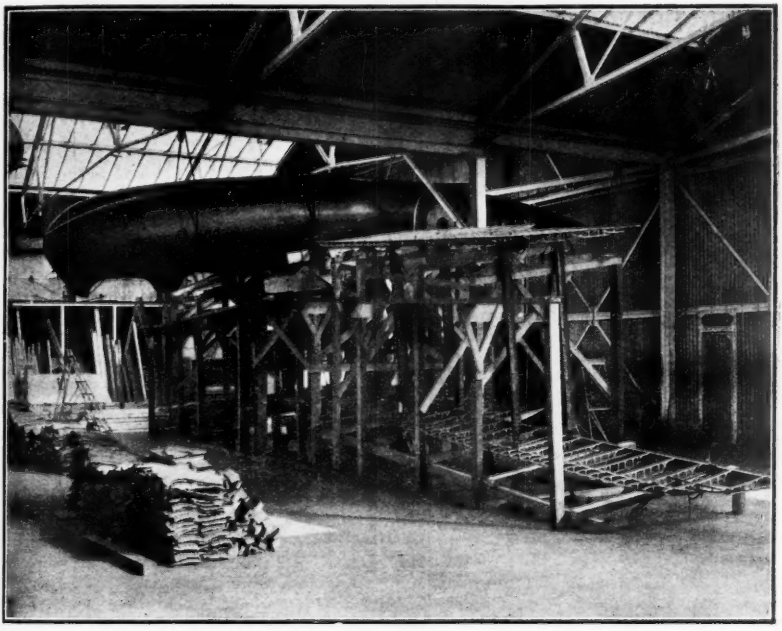


FIG. 20.—*" A.D." boat arranged for test.*

Details.

During test the engine will be removed, and it is then necessary to insert some temporary stiffening members to represent in the fuselage the bracing effect of the crankcase. An iron plate drilled and bolted to the engine bearers is usually sufficient.

Load is applied to the spars of the main planes. The fabric is removed and boards are laid across the front and rear spars. As has already been explained, the presence of new fabric will generally prevent failure of the spars in a direction parallel to the chord. Although such failure might possibly be facilitated by the slacker fabric that occasionally results from weathering in service, the absence of fabric is advantageous since it permits of easy inspection of the

spars, the internal bracing and the fittings during the progress of a test. This is specially important in wood structures, as incipient failure is frequently evident a considerable time before collapse. Where the planes are covered with three-ply or metal sheet which forms an integral part of the rib structure, it is necessary to make the tests with the covering in place.

The position of the centre of pressure of the assumed air loading is marked on the boards with chalk. The divisions along the span are also indicated and loading is conducted by placing shot bags in these divisions symmetrically over the centre of pressure line. In the case where the fabric has not been removed, it is necessary to distribute the load along the chord. In such cases it is usual to apply the load in two rows approximately over the spars, the relative values being arranged so that the resultant centre of load coincides with the assumed position for the centre of pressure.

FIG. 21.—*" Y " level and staff.*

Measurements.

Although in many cases the primary object of the test is to determine the ultimate or collapsing load, an endeavour is always made to obtain from the test the maximum amount of information by means of observation and measurement of distortions. Having determined the types of distortion which are to be measured, the method of measurement which will be employed depends on—

(i) The accuracy required;

(ii) Local conditions which may preclude the use of particular methods; and

(iii) Liability to disturbance during test.

In tests of the main plane structure, information can usually be obtained bearing on—

(*a*) The deformation of the framework.

(*b*) The distribution of loads in members.

(*c*) The deformation, etc., of the spars.

(*d*) Bow of struts.

The deformation of the framework (*a*) may be obtained from measurements which give—

(i) The rise or fall of strut points on the top spars.

For this purpose, readings are taken by means of a " Y " level on a graduated staff, the latter being held in a vertical position by an assistant at successive points along the top spars. This apparatus is illustrated in Fig. 21.

(ii) Change of stagger.

This may be measured at the trailing edge of the planes by suspending plumb lines of fine copper wire. The use of a fixed horizontal scale enables fore and aft motion to be measured with reference to the floor. These measurements are made on the top and bottom planes at the strut points. To prevent swinging, the plumb lines are damped by suspension in oil. The arrangement for this measurement is shown in Fig. 22.

(iii) Movement of fittings.

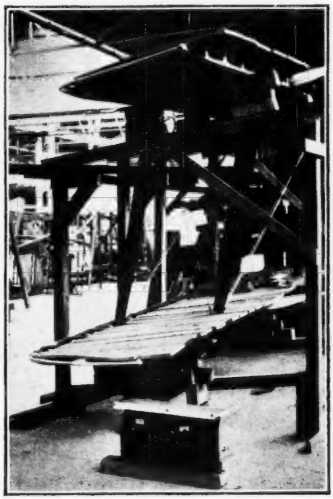


FIG. 22.—*Measurement of lateral movement.*

Where displacement of fittings is anticipated, arrangements can be made to observe and measure such displacements when they occur.

(*b*) *Distribution of loads in the members.*—This may be determined by the use of strain gauges on the wires and cables. The use of tensionmeters has been extensively considered, but no satisfactory form has been discovered. They usually fail on account of—

(i) Inaccuracy;

(ii) Bulk or difficulty of use; and

(iii) The method of measurement involving an alteration in the distribution of load in the structure.

Recourse has, therefore, been made to the simple method of measuring the strain in the member directly by means of a suitable extensometer and calibrating the actual wire and instrument at some previous or subsequent time. Unfortunately, no suitable extensometer seems to be commercially available. At present, the measurement of extension is being made by a simple but somewhat crude piece of apparatus which suffers from the disadvantage that it is liable to derangement during the test. A form of photographic instrument at present in the experimental stage promises greatly improved results.

(*c*) *Deflection of spars.*—The method described in (*a*, i) allows of measuring the vertical displacement of any number of points on the top spars. The points chosen are usually the strut points mentioned above, and others midway between. It is necessary before commencing a test to measure any initial non-alignment of the points of support and, where this non-alignment is excessive, to remove the error by careful re-rigging.

(*d*) *Bow of struts.*—The lateral deflections of the struts are usually measured at the centre of their length.

High Speed Flight.

A test of the main plane structure is often made under conditions representing those which occur during high speed flight at small angles of incidence. The attitude at which the machine is mounted for this test will, of course, differ from that already described, and, in general, the reaction at the tail support will be greater, stressing the rear of the fuselage to a considerable degree.

In other respects the method of test is similar to that described above.

Vertical Nose Dive.

One of the conditions of flight for which a machine is usually stressed by designers is that of flight at low values of lift coefficient when a large moment may act on the planes. Such conditions can be represented in a strength test, but complication of the erection, etc., renders the cost and time involved considerable, and the test is only justified in exceptional cases.

Fig. 23 shows diagrammatically the principal forces which act on a machine in a vertical nose dive at limiting velocity.

(*a*) The moment on the planes; which may be replaced by positive and negative lift forces with a drag component. (The latter for convenience may be applied at the front spar.)

(*b*) The aerodynamic down load on the tail.

(*c*) The air drag on the fuselage and its attachments.

(*d*) The weight of the fuselage and its attachments.

In test these forces may be represented in a variety of ways of which one is shown diagrammatically in Fig. 24. The machine is inverted and the acting forces detailed above are reproduced in the following way:—

(*a*) The forces on the spars, by a suspended distributed load, to represent the lift component on the rear spars, the distributed reaction of a lever suspension system to represent the down load component on the front spars. The latter reaction is suitably inclined towards the rear to represent also the drag component.

(*b*) The reaction of a vertical sling support represents the aerodynamic down load on the tail.

(*c* and *d*) The fuselage is drawn forward so that the suspensory system referred to in (*a*) is inclined at the desired angle. The direction and attachment are arranged so that the reaction represents the resultant of the air drag and of the weight of the fuselage and its attachments.

In order to prevent the weight of the fuselage parts from affecting the distribution of the various reactions, a suitable supporting force of constant amount is applied throughout the test.

A full description of such a test is given in Advisory Committee for Aeronautics Reports and Memoranda No. 588.

Down Load.

Occasionally a test is made under conditions representing down load on the main planes such as might be experienced during inverted flight or under certain

abnormal circumstances. The method of test is similar to those described above, with the exception of the necessarily changed attitude of the machine.

Auxiliary and Controlling Surfaces.

Owing to the absence of detail information as to the distribution of air pressure over ailerons, elevators, tail planes, etc., tests of these parts employ loading which is somewhat arbitrary.

Ailerons, Elevators and Rudder.

It is usual, when testing these members, to include in the tests their respective controls. The aeroplane is mounted so that the part under test, when in its

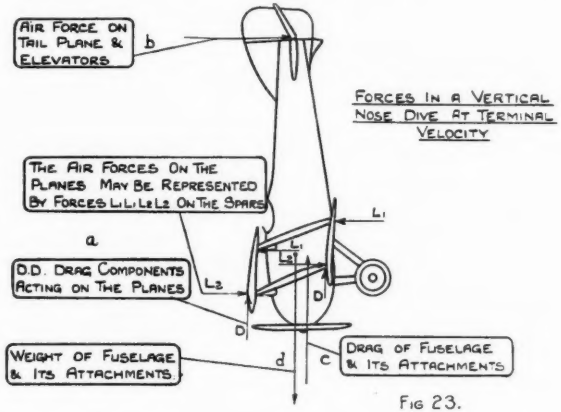
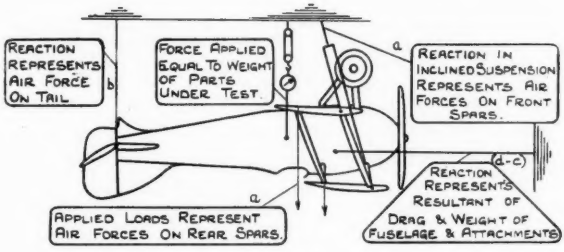

AIR FORCE ON TAIL PLANE & ELEVATORS
b
FORCES IN A VERTICAL NOSE DIVE AT TERMINAL VELOCITY
THE AIR FORCES ON THE PLANES MAY BE REPRESENTED BY FORCES L1 L1' L2 L2 ON THE SPARS
L1
L1'
a
D.D. DRAG COMPONENTS ACTING ON THE PLANES
L2
D
D
WEIGHT OF FUSELAGE & ITS ATTACHMENTS
d
c
DRAG OF FUSELAGE & ITS ATTACHMENTS

FIG 23.


REACTION REPRESENTS AIR FORCE ON TAIL
b
FORCE APPLIED EQUAL TO WEIGHT OF PARTS UNDER TEST
a
REACTION IN INCLINED SUSPENSION REPRESENTS AIR FORCES ON FRONT SPARS.
(d-c)
REACTION REPRESENTS RESULTANT OF DRAG & WEIGHT OF FUSELAGE & ATTACHMENTS
a
APPLIED LOADS REPRESENT AIR FORCES ON REAR SPARS.

MACHINE MOUNTED FOR TEST TO REPRESENT NOSE DIVE. FIG. 24.

normal relative position, is horizontal. A distributed load is applied by means of shot bags so arranged that the centre of gravity of load is everywhere one-third of the distance from the leading to the trailing edge of the member. The leading edge is usually the hinge joint except at balanced portions. This procedure is, of course, based on the assumption that the loading is roughly triangular. The distribution along the span is uniform except near the ends where it is graded off arbitrarily.

The controls are so adjusted that at the commencement of test the member is tilted above the horizontal position. The application of load causes the controls to stretch so that when the failing load has been reached the member has dropped

to or below the horizontal position. The controls are secured by a cable attached to a spring balance which indicates the force which the pilot would have to exert to hold the member under the assumed condition of load.

Experience in aeroplane design shows that if ailerons, elevators or rudders of conventional type will support a load distributed as above and having an average intensity of 20lb. per sq. ft. they are not likely to fail in service.

It is frequently noticed, especially in the case of rudders, that although at the start of the test the controls are secured at the limit of their travel so that the controlling surface is in an extreme position, stretch of the control cable and the general deflection of its attachments are sufficient to allow the loaded control surface to drop below its median or neutral position. Where the aerodynamic loading is largely a function of the angular displacement of the control surface from its neutral position (as is the case for a rudder) it is evident that at no time in flight is the member likely to experience a loading as great as that applied during the above test. It is therefore of interest in rudder tests to measure the change in angle of the rudder for various loads, the rudder bar being secured at the limit of its travel.

Tail Planes and Fins.

It is usual to test tail planes by loading their rear spars or the hinges of the elevators. This is in default of definite information as to the typical or particular distribution of air loading on the tail plane and elevators under average or worst conditions.

Where details are available as to the actual or probable distribution of air load, suitable tests are devised, each case being considered on its merits. Such tests are of special importance where the leading edge of the tail plane is more flexible than the remaining portions.

Fins are usually loaded at the same time as the rudders. The distribution is arbitrary, but the average intensity of loading is kept the same on fins and rudders and on the fins the load is distributed more or less uniformly.

Failure of fins under these conditions is not very usual, but neither is it usual in service.

Fuselage.

To some extent the fuselage is tested during the tests of the main plane structure. The central portion is stressed severely by the "stalling" and "high speed" tests. The latter imposes large strains on the rear portion also, while the former will tend to show up any abnormal weakness in the engine mounting.

A further test of the rear portion of the fuselage is frequently combined with the test of the tail plane. In this case the fuselage is usually supported at the attachment of the rear spars of the bottom main planes and held down at the engine bearers. The lateral strength of the fuselage is tested during the test of the rudder and fins; the fuselage being again supported at a section in line with the rear spars of the bottom main planes and held down near the nose. It is unusual for a fuselage to fail before the rudder.

The distortion of the framework is usually measured at certain leading points. Movement or other distortion of the fuselage fittings is carefully watched.

When monocoque fuselages are under test it is a matter of some difficulty to record the indeterminate distortions which occur in the skin while the test is in progress. These usually take the form of bulges or depressions. If, as is usually the case, the light falling on the fuselage has a preponderating direction, definite shading of the undulations will be produced. This may, if desired, be accentuated by suitable placing of the fuselage and control of the light. During the test any

undulation may be recorded by marking the contour of the high light with white chalk and the contour of the shadow with black (or coloured) chalk. If necessary, successive contours can be added as the distortion increases and each line may be numbered or marked for identification. Subsequent to the test, the fuselage may be photographed (or drawn) and the white and dark contours will accentuate the effect of the shading or, if the removal of stress has allowed the distortion to subside, the chalk lines in themselves will give a sufficiently good effect of relief to register the form of the distortion.

The Albatross three-ply fuselage distorted by down load on the tail is shown in Fig. 25 and will illustrate the above remarks.

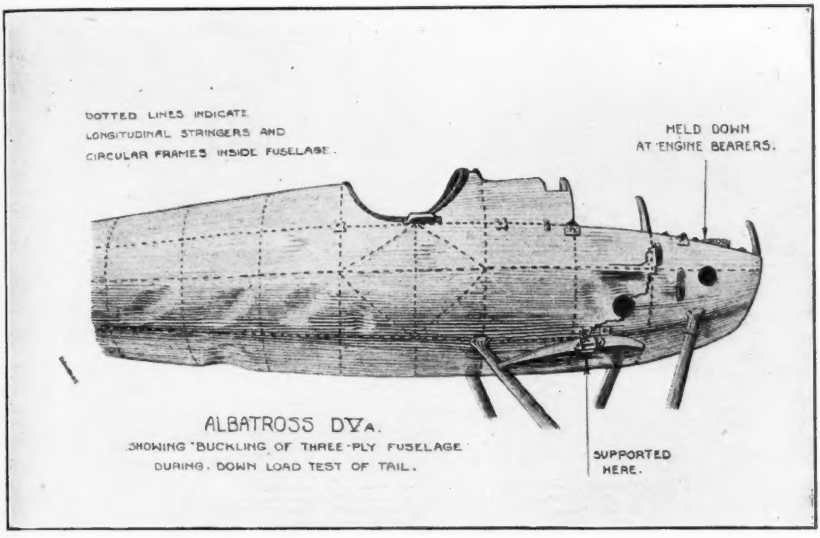


FIG. 25.—*Distortion of monocoque fuselage.*

A pure torsion test is frequently made in which the fuselage is secured (against torsion) at some section near the attachment of the rear spars and is subjected to two forces symmetrically applied to the rear spar of the tail plane on opposite sides of the machine; the forces acting in opposite directions and thus constituting a simple couple.

A method of applying these forces is shown in Fig. 26.

The rotation and distortion of several cross sections of the fuselage may be measured.

Undercarriage.

A full consideration of the various conditions of stress which may be experienced by an undercarriage during landing is somewhat outside the scope of the present paper. A few typical cases only will be considered. The probable limits of variation of the direction of landing reactions in the fore and aft vertical planes applied to the axle through the wheels may be represented by the conditions of (*a*) a landing which has been successfully "flattened out" and (*b*) a "pancake" with no forward component of velocity.

In Fig. 27 are shown the reactions for a case intermediate between (*a*) and (*b*). When the wheels first touch the ground the machine will have a velocity V along a path making an angle ϕ with the horizontal. For convenience this velocity may be considered as resolved into its horizontal and vertical components. As the machine moves forward the flexible parts of the undercarriage are compressed and the vertical component of the velocity is reduced. The wheels at first contact are not rotating and there must necessarily be slipping between the tyres and

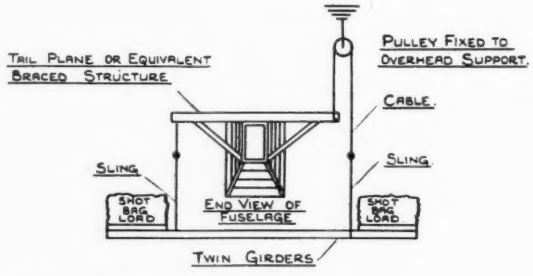


FIG. 26. TORSION TEST OF FUSELAGE.

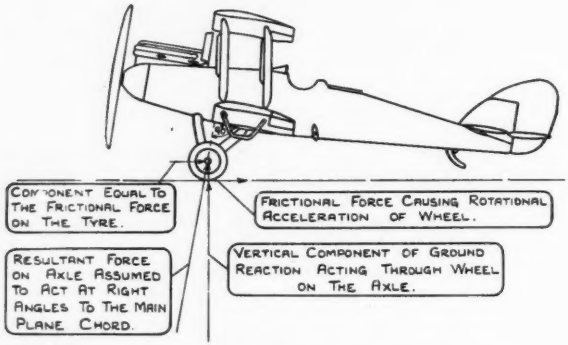

COMPONENT EQUAL TO THE FRICTIONAL FORCE ON THE TYRE.
FRICTIONAL FORCE CAUSING ROTATIONAL ACCELERATION OF WHEEL.
RESULTANT FORCE ON AXLE ASSUMED TO ACT AT RIGHT ANGLES TO THE MAIN PLANE CHORD.
VERTICAL COMPONENT OF GROUND REACTION ACTING THROUGH WHEEL ON THE AXLE.

FIG. 27.
DIAGRAM OF LANDING FORCES ASSUMED FOR TEST.

the ground. The wheels will commence to revolve and will gain speed quickly, but slipping will persist until the peripheral speed of the tyre is approximately equal to the forward component of velocity. The stage at which this slipping will cease and the maximum frictional force which will act on the tyres will depend on many factors of which the principal are:—

(*a*) Vertical and horizontal components of velocity.
(*b*) Mass of machine.
(*c*) Characteristics of shock absorbing parts.
(*d*) Polar moment of inertia of wheel and tyre.
(*e*) Coefficient of friction between tyres and ground.

It is of interest to calculate maximum friction forces for various assumed landing conditions, but unfortunately no reliable values for the coefficient of friction between tyres and aerodrome (or other) surfaces are available. Some simple

experiments made at the R.A.E. using light loading and grass surfaces indicated a value of about 0.64. Assuming values of this order we get for a machine of total weight 3,000lb. the following total horizontal forces acting on the wheels before slipping ceases.

Vertical component of landing speed. ft. per sec.		Assumed coefficient of friction.		Max. value of horizontal force. lb.
3	...	0.3	...	876
—	...	0.7	...	2044
15	...	0.3	...	4380
—	...	0.7	...	10220

The forces on the axle may therefore include a large horizontal component and the resultant will then be inclined backwards to a considerable extent.

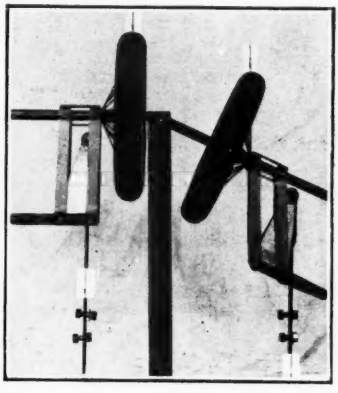


FIG. 28.—*Axle test apparatus to represent effect of wheel inclinations.*

In case (*b*) the rotation of the wheels is a negligible factor and the direction of the reaction may be inclined forward.

Superimposed on these conditions may be unequal distribution of load between the wheels due to landing wing down or on sloping ground and lateral forces due to drift or yaw.

The direction of resultant load on the undercarriage at any instant may therefore vary within wide limits. Certain particular cases are assumed for test purposes, and where one test only is to be made, it has been the practice to apply load so that the resultant force acting on the axles will be normal to the chord of the bottom planes where the latter are attached to the fuselage.

Static tests are made by applying load to the axles, the fuselage being inverted and mounted with the chord of the bottom planes horizontal.

Where the stiffness and strength of the axle for a machine of the usual conventional type are to be demonstrated, it is necessary that the points of application of the load should travel outwards with increase of load to represent the effect of the splaying of the wheels during landing.

This can be effected by the use of a simple link mechanism such as that illustrated in Fig. 28. Such a construction is stable in use and operates satisfactorily.

It is usual to measure distortion of the axle and extension of the shock-absorbing devices and also to observe closely the behaviour of the various joints, struts, etc.

The general arrangement of a static test of an undercarriage is illustrated in Fig. 29.

Dropping tests.—The accuracy of the results obtained from static tests of undercarriages is sometimes questioned on the basis that the time element is important. Where hydraulic or pneumatic energy-absorbing devices are fitted, the effect of rate of loading is all-important and static tests are, of course, useless. In such cases dropping tests may be made.

A simple form of dropping test may be arranged by attaching the under-carriage (either whole or in part) to a hinged pair of shafts as shown in Fig. 30.

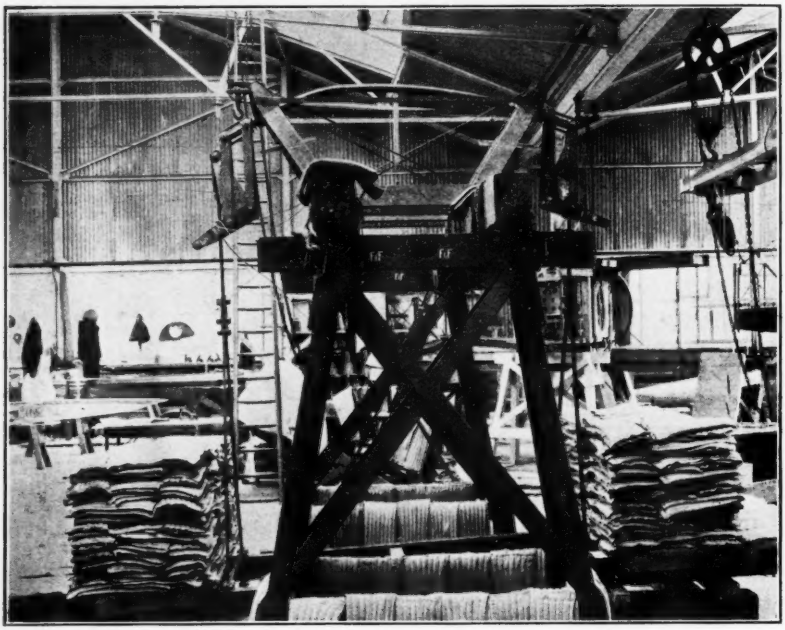


FIG. 29.—*Static test of undercarriage.*

These are arranged to swing about a pivot "A," and provision is made for a load of shot bags to be placed (at "B") over the wheels so that the static load on the latter is equal to the normal weight of the aeroplane. The whole may be lifted by suitable means and dropped by a quick release "C." The impact of the wheels is usually received on strong platforms which can travel on rollers in a direction parallel to the axle, thus allowing the wheels to "splay" as the axle bends. It is, unfortunately, impossible to calculate for the wheels at any instant during landing, their exact inclination to the vertical planes parallel to the direction of flight, on account of the imperfect data available, but it appears probable that in most undercarriages of the type under consideration, the wheels are not only free to splay (*i.e.*, no lateral forces acting on the tyres) but may even be subjected to forces tending to increase the splay, due to bending of the

axle in a horizontal plane causing the wheel tracks to diverge. The use of rolling platforms, however, is simple, and is probably a close approximation to typical cases.

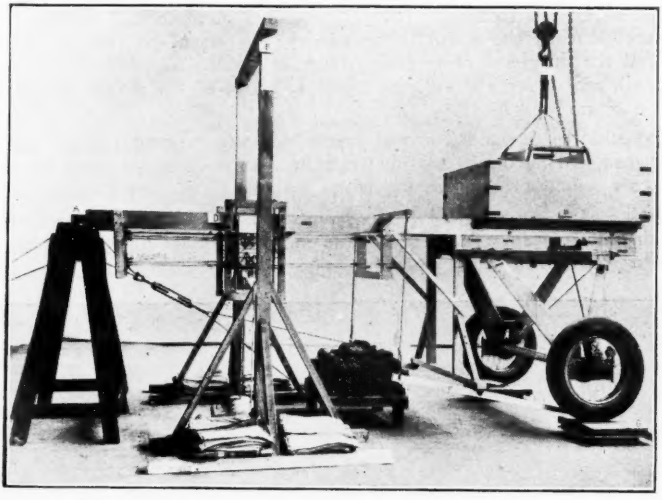


FIG. 30.—*Dropping test of undercarriage.*

During the actual drop it is somewhat difficult to observe and record the relative distortions of the various parts of the undercarriage at different stages of the action. One method is to use autographic record, taking suitable precautions to prevent errors due to deformation of parts under the high acceleration forces. Autographic apparatus is illustrated in Fig. 31.

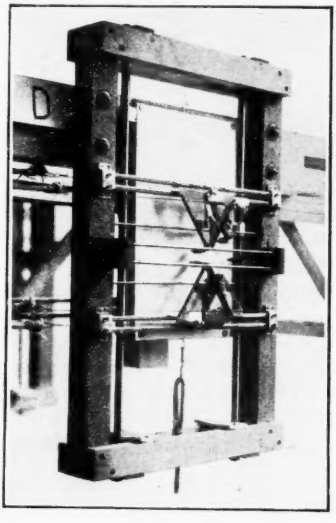


FIG. 31.—*Autographic recording of distortions during impact.*

In the case of energy-absorbing devices, where the time rate is of vital importance, it should be remembered that a dropping test as described above does not accurately reproduce the conditions which occur during actual landings, even though it be arranged that the vertical component of velocity at impact be the same in the two cases. This is because, in a normal landing, the lift on the planes during the event is approximately equal to the weight of the machine, and for purposes of test the machine should be considered as a body having a mass and a vertical velocity equal to those of the actual aeroplane, but having little or no weight.

It is possible to devise a form of test which will represent those conditions, but the expense will hardly be justified, as the results obtained from the ordinary dropping tests will not be much in error.

Rib tests.—The tests of the main planes described above do not determine the strength of the ordinary ribs since the load is applied directly to the spars. Supplementary tests are therefore necessary.

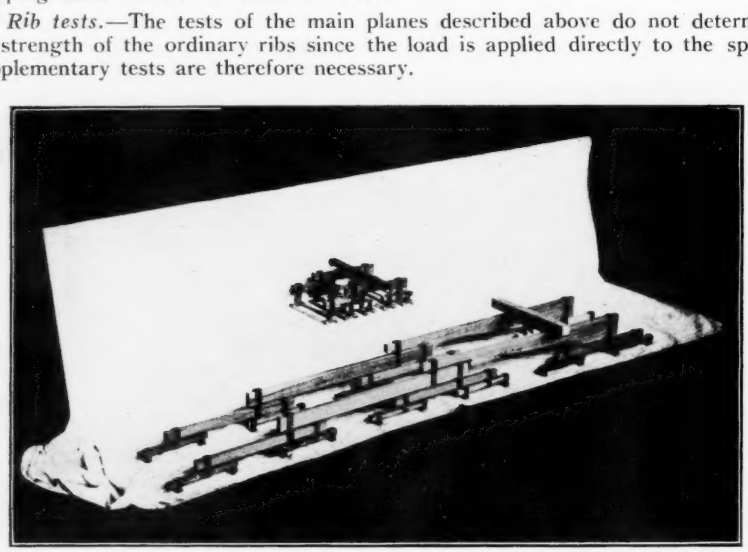


FIG. 32.—*Pivoted levers for rib test.*

The chief difficulty lies in deciding the distribution of the loading on the rib. This is influenced by three main factors :—

(*a*) The distribution of air forces.

(*b*) The re-distribution of these forces through the medium of the fabric (or other covering) to the ribs, either directly, or through the leading and trailing edges.

(*c*) The stresses introduced by the initial tension of the fabric.

For the purpose of test, the distribution of air forces must be chosen on the basis of the best data which may be available for the particular or similar wing sections. The stresses introduced by the initial tension of ordinary doped fabric are considerable, but cannot be estimated with any accuracy, and the safest method of allowing for the effect of these stresses is to reproduce them by covering a test section of plane, taking precautions to ensure that the dummy end ribs are very stiff so that the flexibility in the direction of the span compares with that of a full-size plane.

If load could be applied to the surfaces of the plane distributed like the assumed air forces, a satisfactory test could be made, but unfortunately there is

no simple method of loading a surface (itself curved and somewhat flexible) according to a predetermined distribution, which usually includes some steep load gradings.

At the same time it is extremely difficult to calculate the distribution of stresses in the covering of a plane subjected to air forces, and assumptions must again be made to simplify the process of estimating the distribution of forces on each rib due to the air loading on the fabric. The method of calculation usually adopted for this purpose and the method of applying load to two ribs during test by a duplicated set of levers is described in Advisory Committee for Aeronautics Reports and Memoranda No. 344. The adjustment of these levers has, however, been simplified by the use of the pivoted fittings shown in Fig. 32. An illustration of a typical rib test is given in Fig. 33.

An exceptional case occurs with the distribution of load on a plane (of section similar to, say, R.A.F. 14 or 15) flying at high speed and small angle of incidence. In this case the approximate distribution of normal air forces is

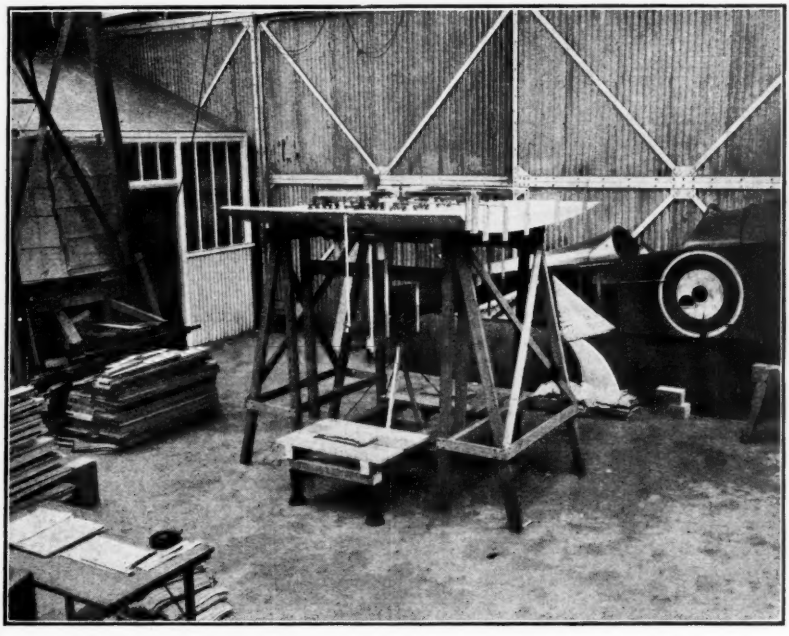


FIG. 33.—*General arrangement of rib test.*

shown by the full line in Fig. 34. Assuming that the static pressure in the plane is determined by the vent holes and that the latter are on the under surfaces at or near the trailing edge, it will be seen that the air forces on the top surface are considerable, but that those on the bottom surface vary from positive to negative and are nowhere of great magnitude. No serious error will be introduced if, for test purposes, these small air forces on the bottom surface be added algebraically to those on the top surface as shown by the dotted line in Fig. 34.

It will also be seen that the grading of the load is nowhere very steep. Under these circumstances the test may be made by inverting a section of plane,

supporting at the spars, removing panels of fabric from inter-rib spaces on the bottom surface, and applying a load of loose shot to the top surface.

The distribution of the shot may be effected with sufficient accuracy by dividing the loading space into cells and placing calculated amounts of shot in each cell at each increment of loading. It is not intended to encumber this description with details of the technique which has been developed and adopted for facilitating the process of loading, but it may easily be imagined that the speed, accuracy and general success of the test depend largely on the employment of methodical and simple methods which may largely be reduced to a matter of routine.

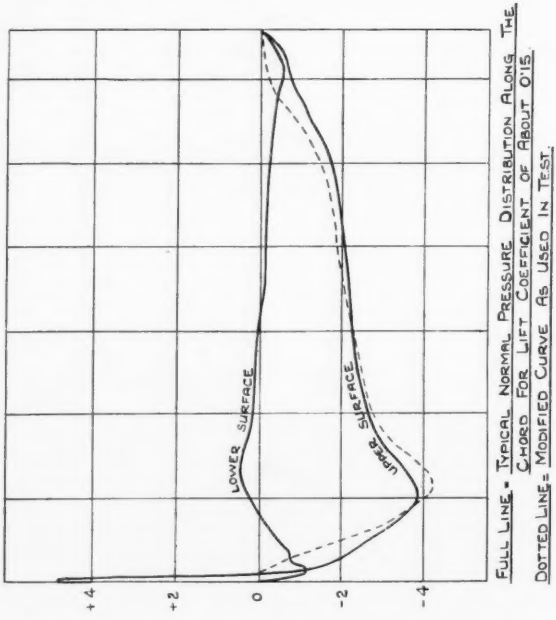


FIG. 34.
PRESSURE DISTRIBUTION ASSUMED FOR RIB TEST TO REPRESENT CONDITIONS OF HIGH SPEED FLIGHT.

Shot Bags.

The type of shot bag employed at the Royal Aircraft Establishment has proved so satisfactory in use that a short description may be of interest.

The weight of each shot bag is 25.0 lb.

The strong fabric case ("No. 8 fell canvas") is divided into a series of longitudinal compartments by rows of stitching 1½in. apart. These, when the case is filled with shot, give the whole a ribbed appearance and prevent any motion of the shot particles. The overall dimensions of the open shot bag are about 36in. by 8in. By leaving a zone free from shot midway along the length, the bag can be folded so as to occupy a space about 18in. by 8in. by 1.38in., the latter being the average vertical height of each folded bag in a pile.

When a concentrated load is being formed, it is inadvisable to allow the height of the pile of shot bags to exceed the smaller dimension of the base on which it is formed. Since shot bags have an aggregate weight of about 218 lb. per cubic foot, or occupy 4.6 cubic feet per 1,000 lb., the size of platform necessary for any given load may easily be determined.

For stability of the load it is advisable that the pile of bags should be "tied" by altering the direction of "lay" of each succeeding layer.

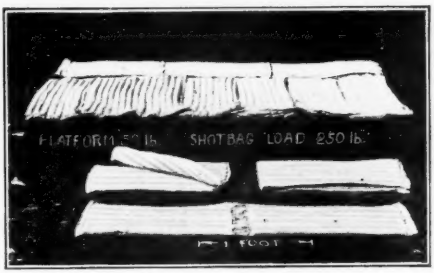


FIG. 35.—*Shot bags.*

The dimensions of loading platforms should be so proportioned as to allow of suitable arrangement of the bags. A typical platform is illustrated in Fig. 35.

A larger number of alternative arrangements would be available if the breadth of the shot bag were some even multiple of the length.

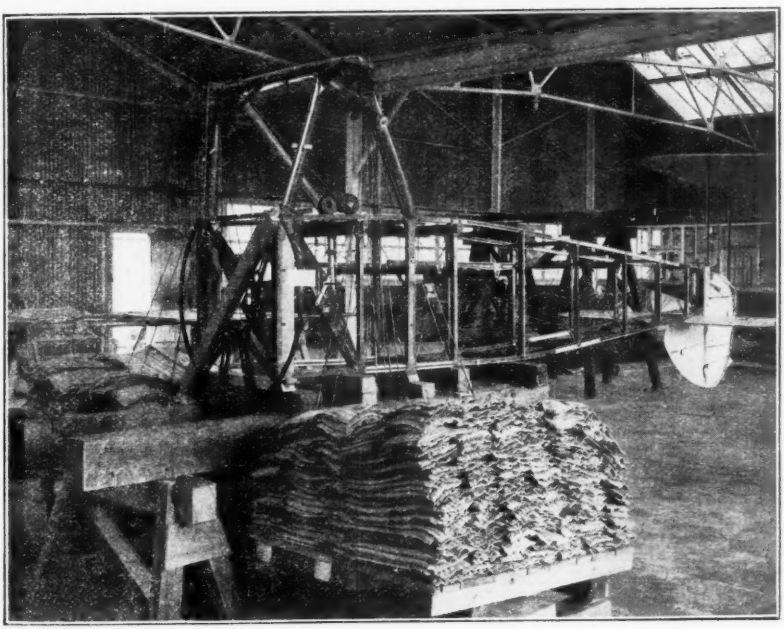


FIG. 36.—*Shot bags as concentrated load.*

The volume occupied by a concentrated load may be visualised by the aid of Fig. 36, which represents a comparatively early form of undercarriage test. The pile of shot bags in the foreground has a weight of 6,500 lb. or 2.9 tons.

Where large concentrated loads are employed, it is necessary to take certain precautions to ensure the safety of the personnel. Where possible, the loads should be kept near to the ground. Where this is not feasible, timber, or other supports, should be arranged to prevent any large displacement of the load at the time of collapse of the structure. An endeavour should be made to provide not merely for all likely, but for all possible, forms of failure in the structure. A clear open space should always be provided to ensure a quick line of retreat in case of emergency, and it should be remembered, when deciding the clearance between the load and the safety supports, that during the collapse of the structure the load may only subside locally and a very small inclination may be sufficient to start slipping of the pile of shot bags.

The paper having been read, the CHAIRMAN said it was a valuable document to be added to the many interesting records which existed in the Society's Journal, and he was sure it had proved instructive to those who had listened to it. He called upon Dr. Sutton Pippard to open the discussion.

DISCUSSION.

Dr. SUTTON PIPPARD agreed that Mr. Douglas's paper would be of extreme value in the records of the Society. To have at first hand Mr. Douglas's ingenious methods for testing aircraft would be of great value to all interested in structural work, and also to students working on the subject. Destruction tests seemed to fall into two distinct types. There was the first class of a more or less routine nature made on a particular type of aeroplane to determine how it behaved, or how it might possibly behave, during its career. The strength of the main structural parts of such an aeroplane could be calculated with a fairly high degree of accuracy, but there still remained the question of fittings, and the occurrence of failures which it was impossible for the designer to foresee, and in the majority of photographs shown that evening it was evident that that type of failure had taken place. That class of test was also extraordinarily valuable for dealing with unusual structures. Mr. Douglas had referred to some tests he made for the nose-diving case, in which there was an extraordinary condition of loading, and he (Dr. Sutton Pippard) remembered him putting up that test for a particular structure which it was almost impossible to calculate. He had put up the test on the actual machine and had shown its actual strength. That was an extremely valuable test, and he was glad it was on record as an official publication. Then there was another thing that the tests had brought out, and that was the variation of flexibility of the structure, which was important, and could not very well be calculated. Reference had been made by the lecturer to the readings that were taken during the course of the tests on the deflection in the plane spars and the bowing of the plane struts. Mr. Douglas must have an extremely valuable collection of that data, and he (the speaker) was wondering whether use was being made of that, or whether it was just filed away. The time had now come for a very careful analysis of that data to be made. In addition to those tests, there was a class of test which actually fell under the heading of research, and was specially typified by the question of undercarriages. The undercarriage question was an extremely wide one, and a

good deal of what Mr. Douglas had said might be open to argument. In any case, research on a big scale was required before the design of undercarriages could be put on anything like the same basis as the design of other parts of the structure. The static test was arbitrary, and, as Mr. Douglas had said, practically useless in the case of some energy-absorbing devices. On the other hand, the dropping test did not appear to him (the speaker) to be over-satisfactory. If one happened to hit on the right drop, which just caused failure of the undercarriage, it was something definite; but if one increased the drop step by step it could not be said what the actual strength was before the test was begun, and that was what was required. Another point was that in testing, Mr. Douglas allowed one-seventh of the lift forces for drag for all centre of pressure conditions. He believed that this was not quite in accordance with the method used in calculation. It would be interesting to know whether the official calculation methods and official test methods were slightly at variance on that point. With regard to the second slide of failures shown by the author, in which the spars collapsed sideways together, he would like to know whether the author had found that type of failure at all frequent. He had only known it to occur twice—once on a very old type of quadruplane, and once in a deliberate test he had made in order to get that condition. In the particular case shown, he believed the fabric would have been a distinct advantage had it been on. He again thanked Mr. Douglas for his paper.

At this point, the CHAIRMAN suggested that the Secretary should be asked to write round to a number of designers of different aircraft asking them for written contributions to the discussion. He would very much like the discussion to be a full one, and the record of the makers' views would be of great value to designers and to people who had to test aeroplanes hereafter, and would probably be welcomed by the Air Ministry and the Royal Aircraft Establishment.

The suggestion met with approval.

Mr. MCKINNON WOOD congratulated Mr. Douglas on the very clear way in which he had given the account of his work. There was no one who could speak on structural tests so well as Mr. Douglas, because he had practically a monopoly of that kind of work. Some of the illustrations served to give an idea of the amazing ingenuity he brought to bear on the invention of gadgets and apparatus for this sort of test. To realise it to the full, one had really to go to his Department at Farnborough and see the wonderful gadgets he had, some of which were extraordinarily simple in construction, and that was where he showed his real skill. With regard to undercarriage testing, we were still very much at the beginning, and he was inclined to think that in the design of undercarriages also we were still in the early stages. The improvement of undercarriage design depended upon the development of methods of testing. There were a great many things in connection with undercarriages about which we knew very little; in fact, we knew very little about what happened when the aeroplane struck the ground. He had tried to get some information as to the effects of landing with drift on the forces on the wheels, whether the side force on the wheel was independent of the angle of drift, or how it depended on this angle, but he had been unable to reach any conclusion. We wanted to know under what conditions tyres were torn off wheels. He seemed to remember having been told by a tyre designer that the tyres could not be torn off, but that the wheels would collapse first, but tyres do come off. There were a great many points of that nature on which information was wanted, and we should have to settle down and develop apparatus for testing undercarriages out in a way which would really represent a landing. It might be a complicated piece of apparatus, but he believed it quite likely that it would be developed.

Mr. W. O. MANNING said it would be a very good thing if more illustrations of those peculiar types of failure could be circulated for general information.

For instance, some peculiar type of failure might happen to one machine, and it would be quite well known to those at Farnborough, but unknown to those who were designing aeroplanes, and the fault might be repeated. Also it had struck him forcibly throughout the lecture how many assumptions had to be made in the calculation of various forces. Various testing establishments had now been going on for 10 or 15 years, and yet we knew nothing of pressures on the fin or on the rudder. The same thing applied to a very large number of other aerodynamic forces on a machine. This fact was illustrated very forcibly by the number of assumptions which the lecturer had to make.

The paper is one of very great interest, the cases of failure shown all deserve the careful attention of those engaged in design, and it is difficult to rate too highly the ingenuity shown in devising the various tests.

Colonel W. D. BEATTY congratulated the lecturer. There was one thing upon which he had been too modest to lay stress, and that was the very large amount of work that must be involved in reducing the various tests to a simple form. The lecturer must have burned the midnight oil in reducing those tests to simple form.

Miss HUDSON pointed to the extraordinary value of the demonstration of these practical tests to beginners. For the first six months of her own intercourse with aeroplanes, she either had to study objects which were miles up in the sky, or else blue prints, and the first time she had ever got to close quarters with an aeroplane was in Mr. Douglas's hangar at Farnborough. To see the various classes of failure actually happening, either slowly or suddenly, certainly added enormously to one's knowledge. If only for the sake of students, the Department at Farnborough ought to go ahead. Of course, that was a comparatively unimportant part of its work, but it was really of very great value. In conclusion, she wished Mr. Douglas had shown a great many more pictures, but hoped he would give another series at a later date.

The CHAIRMAN proposed a vote of thanks to Mr. Douglas, which was carried with acclamation.

Continuing, the Chairman said that Mr. Douglas had put so much brain work into this science that he had perhaps forgotten that a very great deal of strenuous effort was put into it before his time. The only thing in the whole Paper which he could criticise was the Author's suggestion that the first figure was an indication of the procedure up to 1916. He remembered that in 1912 the first group of shot bags divided by a gap for folding were made by Mr. Cody at Farnborough. In 1912, 1913, 1914 and 1915 they used a cathetometer and dummy level to measure deformations with each increment of load. He was quite sure that if Mr. Douglas had been there he would have improved very much on their procedure, but there was a great deal of work done by men whose names were well known. It was not specialised, and it had suffered from that fact. It would be remembered that Major Green, the late Lieutenant Busk, Major Grinsted and Captain Mayo, and others, did a great deal of work, such as in the extension of deformation tests, and they very carefully investigated the stresses and strains that came upon aircraft in those early days. With that single criticism, which was meant in the kindliest sense, because he looked upon the paper as quite a record one, he repeated the thanks of the meeting for the very excellent paper presented.

Mr. DOUGLAS, replying to the discussion, in the first place thanked the meeting for its patience. With regard to Dr. Sutton Pippard's remarks, he had referred to lateral failures of spars, and had mentioned two cases. He remembered, off-hand, two other cases, but they were both in planes of similar type. In one of those cases the test was carried out with and without new fabric, and the trouble did not occur with new fabric, but did occur when there was

no fabric. The open question was whether it would have occurred had there been fabric which was ageing. That was still an open question, but it was generally agreed that they should not rely too much on the bracing effect of the fabric to prevent that type of failure. In connection with the proportion of lift to drag at stalling incidence, the figure of one-seventh had more or less been blessed by use for a long time, and had been founded on the best information available up to very recently. The error was very small at present, and they were rather waiting for the results of some full scale tests in the air, which were almost ready, before making any drastic change in their method. Mr. McKinnon Wood had expressed alarm at the figure of 10,220, but he (the author) had pointed out that with such a downward velocity (15ft. per second) the machine would probably crash anyhow, and the figure was only of theoretical interest in that case. His figure referred to a particular undercarriage with particular characteristics, but was fairly typical. Mr. Manning had mentioned that there seemed to be rather a lot of assumptions throughout the Paper. That was partly because he (the Author) had taken some trouble to emphasise the assumptions where he could. It was always a safe plan to have before them clearly what assumptions were being made, otherwise, from force of habit, they were liable to forget that they were assuming things and that those assumptions were not always necessarily correct. Also, the assumptions arose in several different ways. They had to assume something generally in deciding what loading probably went on the part under consideration, and they had to assume something occasionally because they could not represent that exactly in their tests, and when the assumptions were all added up and tabulated they did appear to be numerous. Colonel Beatty had referred to the amount of work probably involved in the elaboration of some of the tests. Of course, there had been a lot of work involved, and during the war it meant burning some midnight oil, but he must mention the very able staff that had helped him all the way through, and especially Mr. Clegg, who now looked after the tests almost entirely. The Chairman had suggested writing for the views of designers of prominent aircraft companies on these tests. Such information, if it could be obtained, would be very valuable to those at Farnborough, because they were not always sure, when designers paid them visits, whether they really said what they thought; but, in general, designers and visitors agreed largely with their methods. When they were introducing a special test or a new method they tried to notify the designer concerned beforehand, so that if he did not approve of their methods he could say so in time; but as a rule, he was glad to say, designers approved. The Chairman had also referred to the fact that a large number of the present methods were in existence as far back as 1912. He (the Author) had no wish to suggest originality for present methods, but merely wished to describe them. A lot of these tests, round about 1912, had hardly been reduced to anything like routine work, he believed; they were mostly special laboratory tests, but in many cases present methods had been adopted from those pioneer tests.

The meeting then closed.

Mr. C. C. WALKER (*communicated*): That part of Mr. Douglas' Paper which deals with typical cases of failure is of great interest, and at the risk of seeming greedy when hearing so much of value, an expansion of this part of the Paper would surely have been greatly appreciated by everyone. Mr. Douglas's experience must be unique, and the more obscure types of secondary failure which he has witnessed would be of the greatest interest to aircraft designers. It is difficult to over-estimate the value of the earlier tests to destruction in directing attention to the causes of secondary failure. Once the way in which rather complicated joints were liable to distort had been indicated, it became possible to carry out detail tests on materials and combinations of materials

such as occur when metal has to meet wood under stress, which could form a more certain basis on which to design.

Full-scale strength tests are now practically impossible for aircraft constructors to carry out, and it is to be hoped that it may be found possible to continue this work at the R.A.E. on modern aeroplanes.

There is one point on which information would be extremely useful, and that is the strength of old and much used aeroplanes. Mr. Douglas has, I believe, carried out at least one test on an old machine, but as he did not touch on this in the Paper there was probably no result obtained which was attributable to age.

It must now be easy to obtain military aeroplanes at practically no cost without the engine, of a type which has already been tested new. If it is difficult to obtain a machine with a large number of flying hours behind it, one might be pegged down in the open for three months, or say 2,000 hours exposure to the elements, merely taking the necessary steps to avoid rust or standing water in any part, and afterwards tested to destruction.

It would be a further advantage if a machine could be selected which employed 3-ply wood for structural purposes to some extent.

I should like to press strongly the desirability of such a test, and to ask Mr. Douglas if he has any information on the subject.

As regards testing wings for the terminal dive condition, the application of load to the front spar seems an approximation which is hardly justified, as it is probable that the leading edge or the fabric at the leading edge would be the first thing to go. In any case as usually taken, *i.e.*, a terminal dive without a propeller, the condition is somewhat unreal, and of little practical importance, except as a convenient means of distributing the loads for the purpose of stressing tails, fuselages and perhaps rear spars.

What may be termed self-intensifying stresses due to unstable deflections (*e.g.*, increase of incidence) are difficult to estimate, and only a limited amount of help is to be obtained from strength tests. I believe it is the fact that static tests were carried out at Farnborough to try to account for certain failures of this type without successs.

Mr. Douglas is to be congratulated on presenting a Paper which is a record of such valuable, thorough and accurate work.

Mr. E. G. WALKER (*communicated*): Mr. Douglas gives, in his Paper, a fairly full account of the methods employed at the Royal Aircraft Establishment in testing aircraft to destruction, but he says little about the interpretations which are to be placed on the results of his tests. This appears to the writer to be a phase of the subject which might well be discussed at further length. The destruction of a completed machine straight out of the shops seems, on the face of it, to be an expensive and relatively crude way of testing the fitness of a design, and unless results commensurate with the expenditure and waste of material and labour involved can be obtained, its value may well be open to doubt. It by no means follows that a detail which will stand up satisfactorily to a static loading test of the sort described in the Paper will do so when subjected to the entirely different stressings which obtain under working conditions. An aeroplane in flight may be subjected to much more severe stress conditions than when loaded statically, and its safety involves the consideration of such points as range of stress, time rate of variation of stress, shock, vibration, etc., all of which may produce considerable modifications in the ability of any particular member to carry its working loads. It is obviously impossible to reproduce any of these effects in a static loading test, although, as Mr. Douglas points out, a certain amount of work in this direction has been done in the case of undercarriages. In addition, in many cases the distribution of static load is only an approximation, more or less close. Evidently the effect produced on

any particular member by such a test may only be remotely connected with failure-producing effects in that member under working conditions. Hence considerable caution is necessary in interpreting the results of static tests on aeroplanes. The Author might well supplement his Paper by a statement of what his experience leads him to consider the results of static tests to mean when applied to a machine as loaded under flying conditions.

Mr. B. THOMPSON (*communicated*): Mr. W. D. Douglas's Paper on "Destruction Testing" is a valuable record of the methods at present in use, and of their development. It is therefore the more to be regretted that he has put on one side the whole question of the nature of the air loads coming upon the surfaces of aircraft, since both destruction testing and calculations are useless or the reverse in exact ratio to the accuracy of the assumptions made in respect of these loads.

That the assumptions now made are reasonably correct is shown by the small number of breakages due to normal flying, including stunting, on aircraft built to British load factors. On the other hand, there exists more than a suspicion that these load factors are higher than is necessary for commercial aircraft, and some form of destruction testing that will more closely simulate the dynamic loading of flight conditions seems desirable.

I believe efforts to secure a dynamic loading have been made in the U.S.A. by testing ribs and fabric under water, a section of a plane being mounted under the travelling carriage of a ship model testing tank, and the speed at which collapse occurred noted. The unsatisfactory point about any test of this nature is that the destruction is too complete.

In respect of the surface distortion of monocoque fuselages under load, I would like to know if any experiment has been made in painting such a fuselage in black and white bands or in chequers and photographing it from different angles during the test. As an application of the old gunmaker's method of testing rifle barrels for straightness it might be of interest.

Mr. J. D. NORTH (*communicated*): I am glad to have this opportunity of publicly recognising the valuable work on structure testing for which Mr. Douglas has been responsible. No one reading his Paper can fail to appreciate the conscientious accuracy which has marked his experiments. I am glad to say, however, that though in this country we are well to the fore in the scientific testing of structures, we have not thought a destruction test of a complete aeroplane an essential preliminary to the public use of that machine. If such a regulation were introduced it would throw on the introduction of new machines a financial burden too great to be borne at present.

I feel that testing to destruction is most usefully employed in checking assumptions made in certain complex cases in structural design. A careful examination of detail arrangements, such as is necessary where a detailed check on the strength is to be kept, reveals cases where the designer or his assistants engaged in the work of checking cannot feel confident that the simple engineering approximations possible will give a reliable indication of the strength of the component or detail. Here we have a proper subject for destruction testing which, if properly carried out, will provide a basis for future design, apart from the special verification for which it was intended. In many cases it would be useful to carry out series of tests varying one condition of the complex at a time, in order to furnish a proper relation between cause and effect.

In the early stages of light metal construction a considerable amount of testing has been necessary, but the accumulated data renders possible more and more confident prediction. While design is kept within the boundaries allowed by reasonable deduction from experimental evidence available, it is possible to

economise in test work; but when it is desired to go further afield, experimental aid must once again be called in.

Destruction testing should, I feel, be used as an instrument of research rather than as a mere process of checking. It is true that, in research, experiment is intended to answer a definite question and is not conducted in a haphazard manner; but if destruction testing furnished no more information than that the article tested withstood specified loads, it would not be used to its best advantage.

Mr. Douglas's Paper refers specifically to testing to destruction, but he will, I am sure, agree with me that destruction is not essential to useful testing. In undercarriages in particular testing is required to verify the *assumptions* made in calculation and to improve the technique of design, rather than to measure the load at which a particular undercarriage will fail.

I believe that Mr. Douglas holds the same views, and I trust that he will have adequate facilities to extend his useful work in other directions and on broader lines.

Mr. H. P. FOLLAND (*communicated*): I cannot but endorse the advantages of a Paper such as that of Mr. W. D. Douglas on the testing of aircraft to destruction. It so clearly puts forward the methods of testing, and the results which can be obtained; also the method of testing which gives a result under conditions closely allied to those in flight.

Testing to destruction is all-important to commercial aviation. Under the present conditions of commercial aviation it is vitally essential that tests on a new type should be carried out under the R.A.E. method of testing and procedure. The standard method of checking the machine by the Calculations Department of the Air Ministry does not cover the complete aeroplane, and does not find out the weak spots of the detail design. In many cases the machine is checked chiefly from the point of view of main structure of wings, tail plane and fuselage. Only in very rare cases are the fittings themselves checked in detail and for design generally. It appears to be sufficient to give the loads of the principal members of the structure and to ignore the detail design of the fittings. In many cases in the past machines have been stressed and checked, and yet in flight fittings have been broken, or have collapsed through faulty detail design. Therefore, I am of the opinion that it is absolutely necessary, especially with commercial machines, that one machine at least should be tested to destruction, before any machines are used on a commercial air line, unless they are of a similar design to a type already shot-loaded.

The question of testing materials and joints by means of X-rays has proved extremely useful, and should become vitally important. One use of the X-ray process appears to me to be that of examination of commercial machines after a large number of hours flying. It is necessary, after certain periods, to renew airworthiness certificates. This is generally done by A.I.D. inspection. It is invariably considered too long and too expensive a job to take the whole of the fabric and fittings from the wings, etc., for proper internal inspection. It would, therefore, be useful if some sort of portable X-ray apparatus could be used for the inspection of fittings after service or commercial use; it would then be possible to find out whether joints were standing up to their required work, or were showing any signs of weakness.

Another case which should be considered more carefully is that of initial tension. It is quite possible that calculations will show very little load in certain members, and in other cases some members are redundant.

In redundant members, and in members lightly stressed, there is often a greater load applied due to initial tension, resulting from the trueing up of a wing structure of the fuselage. It is possible to get in the so-called redundant member a load equivalent to 75 per cent. of the total strength of the trueing-up

wire. It would, therefore, be useful to take readings from a tension indicator placed on the redundant bracing wires or lightly stressed wires, then tension up the wire to give a load equivalent to, say, three-quarter strength of the wire, and then make an examination of the resultant forces on the fittings and members adjacent. Over-tensioning of wires is found to cause trouble with fittings and struts due to the parts being calculated to meet the design loads instead of taking the initial tension which may arise from trueing up.

Mr. R. A. BRUCE (*communicated*): As a record of how far the science and practice of conducting such tests has been carried, Mr. Douglas's Paper leaves little to be desired.

It is of course well understood that destruction tests do not give all the knowledge which is required with regard to the possible methods by which an aeroplane can be destroyed by overloading. For instance, it is quite obvious that no light is thrown on the effects of wear and vibration.

With reference to the latter, a fair number of separate experiments have been conducted upon such subjects *inter alia* as to the effect of vibration upon the breaking strength of streamline wires. There is, however, a point of view which it may be profitable to give some consideration to at the present moment. Very simply expressed, the question to be considered is under what circumstances is it possible to indulge in the very expensive luxury of complete destruction tests upon an aeroplane?

There seems little doubt that such tests were fully justified (and could not be described without abuse of language as in any sense a luxury) whenever large numbers of aircraft of settled design had to be put into production. The aircraft industry, however, will recognise that it is two or three years since anything approaching this state of affairs has occurred, and we fear that it may be some years before it is repeated.

The question therefore arises as to whether it is not possible to attain a great deal of useful knowledge by a carefully considered system of applying shot-loading to a full-size aeroplane structure in such a way as to prove it without destroying it. The nearest analogy to such tests I have in mind are those which apply to Board of Trade or Lloyds tests on steam boilers. The application of the load is such as to cause stresses in excess of those normally encountered, but not sufficiently so to dangerously stress the structure. On the other hand, the deflections and yields under such proved load are very carefully noted, and if they exceed certain determined limits the structure is not passed. This may result in the structure being put right by additional staying, or it may call for complete rejection.

Would it not therefore be worth while to thoroughly investigate the possibility of applying a proof load, which should be some multiple of the normal flying load, of the order of 2 or 3, and carefully observe the deflections of the structure under these circumstances, and in particular the tendency of all fittings and attachments to distort? The object of this test would be to allow the aircraft, subject to careful inspection, to be utilised after such tests had been completed. In order to develop the necessary experience it is suggested that whenever aircraft are in future tested to actual destruction the load should be applied in defined stages corresponding with multiples of the normal flying load. A very careful survey for deflections and distortions should be conducted at the end of each multiple loading. The series of observations thus taken should then be carefully compared with the observations when rupture or failure takes place. The object of so doing would be to determine whether fresh light cannot be thrown upon the behaviour of the aeroplane structure when loaded with, say, three times the normal flying load, so as to reveal unsuspected structural weaknesses by the indications of abnormal distortion or deflection.

The importance of this resides in the actual practical limitations to aircraft construction imposed by the financial stringency of the country. No machines are being built in large quantities at the present moment. On the other hand, a fair number of experimental types are being produced in small quantities of three or thereabouts. It seems hardly possible at the present day to destroy one-third of the aircraft produced to learn whether they are safe. Some other procedure should therefore be adopted, and investigation should be conducted with a view to determining how far the kind of proof load advocated can be relied upon.

It may be objected that hesitation might arise in using aircraft structures to which such a proof load had been applied, but I do not think that such can be seriously entertained if the proof load is judiciously fixed with a view to limiting it to such a load as may be expected to occur on exceptional or rare occasions during the actual life of the aircraft considered.

It is not my purpose to make any suggestions with regard to the multiple of the normal load which should constitute the proof load, but it is clear that any machine which is capable of being looped may encounter loads of 3 to $3\frac{1}{2}$ times the normal flying load, and that if the proof load were chosen so as to coincide with about this multiple of the normal flying load, no greater harm could have been done to the structure in the stripped condition where every fitting can be observed than would be encountered by the aeroplane when subjected to this manœuvre but without the possibility of examining the effects of the load applied.

Another point of some importance in testing aeroplanes to destruction arises in connection with the difficulty of applying the loads. The duration of the time during which a structure is subject to load is one of some importance. No doubt it will be within the experience of many constructors that in loading separate units to destruction a load which may be carried for a short time safely will, if the structure is allowed to stand for prolonged periods under it, ultimately cause failure.

NOTES ON THE STORAGE OF AIRCRAFT.

BY P. V. HOARE, A.F.R.AË.S., A.M.I.C.E., A.C.G.I., D.I.C.

GENERAL.

Introductory Remarks.

The storage of aircraft is sometimes regarded as a matter of secondary importance, but to maintain good efficiency and reliability considerable attention must be devoted to the aircraft during the time when it is not actually in flying condition. Storage in an indiscriminate manner leads to a rapid deterioration, with a consequent financial loss and the introduction of other elements which may be exceedingly dangerous when the aircraft is afterwards flown.

A complete aeroplane or seaplane, or any of its components, calls for separate and distinct methods of treatment and these methods have now been formulated, being based chiefly on experience gained by operations of trial and error.

Not only the aircraft, but also the buildings in which it is proposed to store aircraft, must carefully comply with certain conditions, as however much care is taken with the aircraft, a badly constructed or unsuitable building may counteract all efforts to maintain the aircraft in a serviceable condition and be the cause of scrapping valuable machines.

Storage Buildings.

It is therefore necessary that buildings, unless specially designed for the purpose, should be carefully inspected and conform to certain definite principles.

These buildings should, for preference, be of substantial brick construction and be capable of excluding wet. The internal temperature should be maintained fairly evenly at about 60°F. At the same time, an installation to prevent the atmospheric humidity from becoming greater than 60 per cent. is desirable, as the moisture which is deposited when the dew point of the atmosphere is reached may easily find its way into unprotected timber and also lead to the rusting of steel parts. Particularly does excess moisture manifest itself in its action on glued joints in timber to the detriment of airscrews and built up members of aircraft; it is also detrimental to undoped fabric.

To maintain successfully a relatively constant humidity inside a large storage shed is a matter of considerable difficulty, as can be realised when it is considered that the natural humidity of the air outside the shed may vary from 20 per cent. to 100 per cent. (saturation). In winter it is easy to conceive a day when the outside air is at a temperature of say 30°F. and with a humidity of 95 per cent. Under these conditions the interior of the shed would be damp. With the air practically saturated, moisture would be deposited on the material stored and on the walls of the shed. Another possible condition which may follow a few days after that described above might be with the humidity outside the shed as low as 20 per cent. while the interior humidity may be even lower than this, caused possibly by sunshine slightly warming the air inside the shed. This would conduce to stretching of unprotected fabric and warping of timber.

So far no really successful scheme for dealing with this question has been evolved, but various devices are in use and doubtless will be improved as the importance of the question becomes more realised.

A typical modern storage shed is shown in Fig. 1, this shed being fitted with devices for the maintenance of a fairly constant atmospheric humidity.

General Principles.

Given a suitable building, each complete aircraft or its component parts must be placed so that no heavy parts are allowed to hang on weak points of the structure, and all parts must be carefully supported. Loads thrown on the centre of an unsupported span should be avoided as, with timber and in some cases with metal, such an action may produce a permanent sagging and the introduction of stresses which were not allowed for in the design of the structure.

All stored aircraft should be subjected to a periodical inspection of its various parts in order to check deterioration and to maintain it in a serviceable condition. To permit of these inspections, the methods of storage must be such as to give free access to all the principal parts, such as main planes, engines, controls, and when components are dealt with separately, to the individual items.

Many parts of aircraft are very fragile, such as the leading and trailing edges of main planes and the tail control surfaces, and these parts, when the components are stored separately, should be well protected. On the exposed surfaces of metal work a liberal supply of anti-rust composition should be applied, and the parts thus treated should not be allowed to rest against fabric parts.

Where storage space permits, and where a complete aircraft is likely to be required from storage at short notice, it is more convenient to store the aircraft in its fully erected condition so that dismantling and subsequent erection are dispensed with. It is usual, however, to release the loads on as many of the parts of the aircraft as possible, as for example, packing up of undercarriage axles to relieve tyres and shock absorbers.

If an aircraft is to be stored for a long period it is better entirely to dismantle it and to store its component parts separately, as this method permits of a more detailed inspection of the parts and ensures that most of the loads are eliminated which may otherwise produce deformation of certain members. Again, the varied construction and conditions of aeroplanes and seaplanes prevent these aircraft from receiving common treatment as regards storage.

Classification.

In dealing with the particular features and requirements of storage, it is proposed to consider firstly complete aircraft of various types and afterwards components, with typical examples of each case.

The term " complete aircraft " is understood to mean an aircraft in flying condition, containing the necessary fuel, oil and water, and in some cases other adjuncts which may be required for a particular service.

For each type of aircraft the details of these items, excluding liquid load, are laid down in part lists or schedules.

Many of the items, when once fitted, form an integral part of the aircraft, but those which do not come in this category, being usually part of the wireless and instrument equipment, may, when an aircraft is to be stored for a considerable time, be removed and stored separately.

Considering the types of aeroplanes and seaplanes separately, certain inherent difficulties become apparent with each type, but they may be classified roughly into large types and small types of aircraft and the requirements of these classifications studied separately.

For purposes of the above classification the large types are typified by the following :—

Handley Page types O/400 and V. 1500.
Vickers Vimy.
D.H. 10.
F. type flying boats.

And the small types by :—

Sopwith Snipe.
Bristol Fighter.
Avro.
D.H. 9a.
Parnall Panther.
Fairey Seaplane.
Short Seaplane.

It will thus be convenient to deal with aircraft under one or other of these headings and to consider individually the best methods for these classes.

LARGE TYPES OF AIRCRAFT.

Aeroplanes.

As a typical case of a large type and one which calls for rather special and intensive treatment, the storage methods used for a Handley Page V. 1500 aeroplane will be described. This type of aeroplane, although not now in general use, involves practically all the fundamental principles of storage which apply to all large aeroplanes. To appreciate the problem which arises in this case, the over-all dimensions of this aeroplane are given and are as follows :—

Span, wings spread...	126ft. 0in.
Span, wings folded	45ft. 0in.
Length, wings spread	64ft. 0in.
Length, wings folded	74ft. 3in.
Height with tail on trestles	22ft. 0in.
Weight	13.4 tons.

These dimensions indicate the size of the accommodation which must be provided, and it will be seen that a storage shed of ample proportions is necessary, especially if the aircraft is to be stored complete and with its wings spread. With regard to the height, it may be mentioned that this type of aircraft is never stored with its tail resting on the ground, so for roof clearance purposes it must be considered with its tail resting on trestles, that is, with the top longerons of the fuselage approximately level. The size of a storage shed necessary for this purpose can be seen from Figs. 1 and 2; the former showing the exterior and the latter the interior of such a shed.

It will be assumed that an aeroplane of this type has arrived by air and is to be stored as a complete machine. Neglecting for the time being the work necessary in getting the aeroplane from the aerodrome into its correct position in the storage shed, it is proposed to consider the operations which have to be carried out to meet storage requirements.

A specific sequence is given to these operations and forms a rough guide as to the order of the work. It is possible, however, that two operations may be carried out simultaneously; for instance, the instruments may be removed while the main planes are being slung.

These operations will firstly be summarised and then described in detail, and they are as follows :—

(1) Rest tail of the aeroplane on a trestle about 9ft. high, and place two other trestles under the fuselage, one under the bomb bay and the other under the pilot's seat.
(2) Take the weight off the undercarriage wheels by supporting each end of the undercarriage axles on special packing blocks.
(3) With the main planes folded sling the lower planes from chains supported by standards resting on the floor of the shed.
(4) Strap ailerons, elevators and rudders in normal position.
(5) Drain all petrol, oil and water from tanks and systems.
(6) Clean all the outside parts of the engine and coat these parts with vaseline or other suitable anti-rust preparation.
(7) Remove the magnetos.

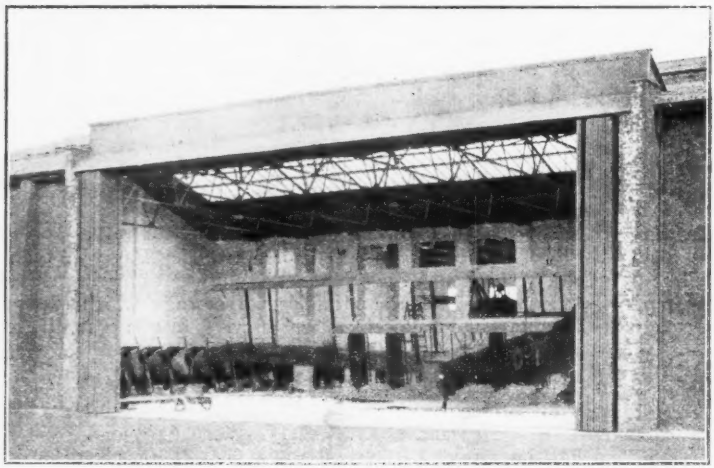


FIG. 1.—*Aircraft Storage Shed.*

(8) Clean and grease throttle and magneto controls, especially at the hinges.
(9) Clean engine valve springs and grease guides and stems where possible.
(10) Dismantle and clean the carburettors, then re-assemble, closing all external apertures to prevent any ingress of grit or dust.
(11) Cover exhaust manifold and engine breathers with fabric.
(12) Carefully secure engine covers so that they completely enclose the engine and place drip trays under each engine to collect any oil residue.
(13) Clean down the main planes under the engines.
(14) Grease all control wires and pulleys.
(15) Remove wheels and clean and grease hubs and axles, and afterwards clean each undercarriage.
(16) Clean and grease all external bracing wires.
(17) Wipe down the fabric surfaces.

It is proposed now to amplify the foregoing summary and to show how each of the operations may be carried out.

The main planes of the aeroplane will usually be folded before it is taken into the shed and it will have its tail resting on a transport trolley.

In the execution of operation No. 1, it is necessary to place chocks before and behind each of the wheels of the undercarriages to prevent any fore and aft

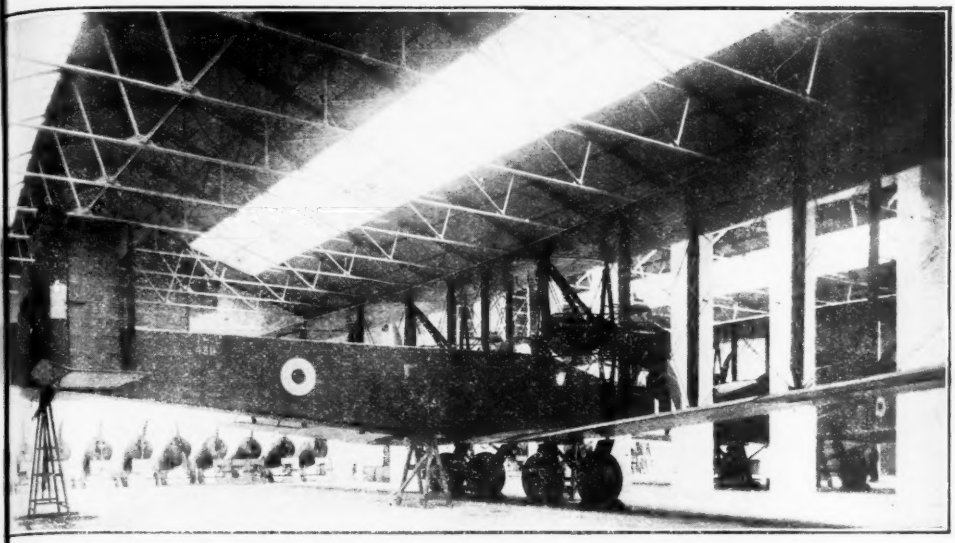


FIG. 2.—*Interior of a Storage Shed.*

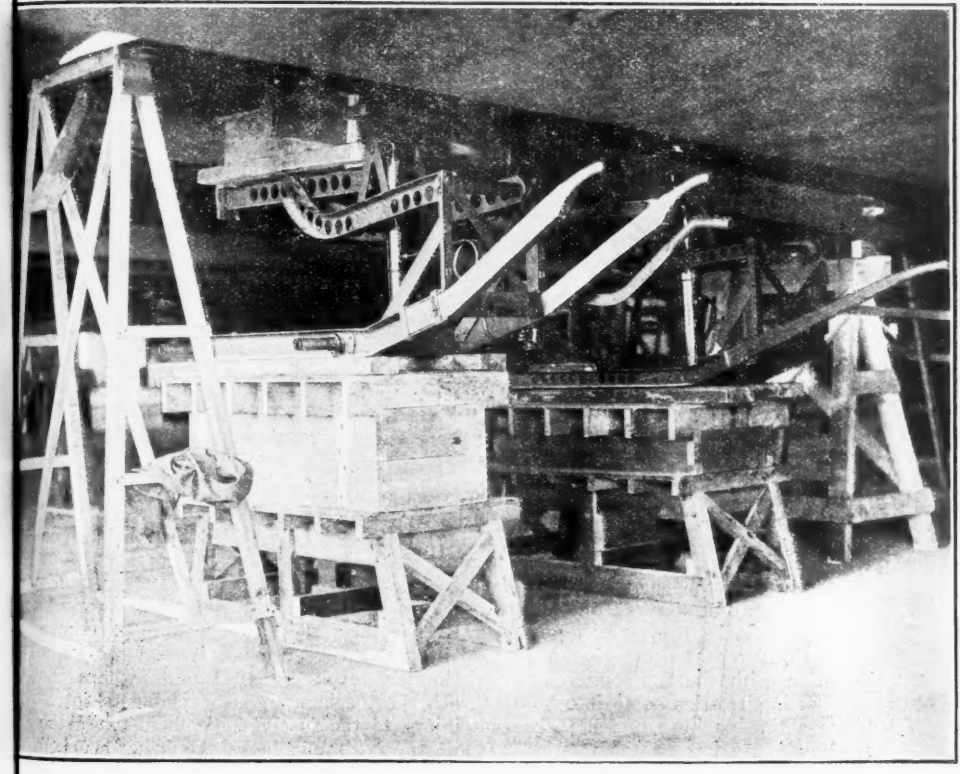


FIG. 3.—*Wooden Cradle and Lifting Jacks (with wheels removed) for lifting large Fuselage.*

movement of the aircraft when the tail is being lifted. Owing to the weight of this type of aeroplane, mobile hydraulic jacks are used. These jacks are wheeled under the rear portion of the fuselage and on them is laid a strong wooden cradle built up as shown in Fig. 3, the end of the cradle coming just in front of the tail skid. It is very important that the weight of the fuselage should only be taken in this manner as local loads incorrectly applied lead to distortion and possible rupture of the McGruer longerons. Operating the hydraulic jacks then raises the tail of the fuselage from the trolley, and when clear, the trolley is removed and a small trestle placed under the tail skid. When the full travel of the jacks has been completed other trestles of suitable height should be placed under the

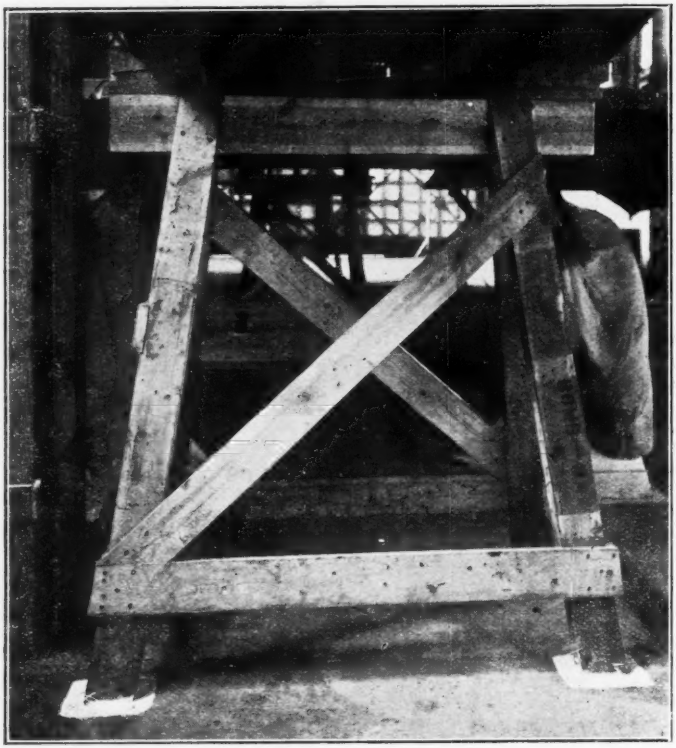


FIG. 4.—*Fuselage front Trestle.*

middle and front portions of the fuselage at the points specified by marking on the fabric. By the use of wedges and packing pieces adjustments should be made so that the weight of the fuselage is carried on the trestles, after which the load may be lowered off the jacks. Then by placing other packing supports under the jacks they may again be raised to meet the fuselage and the above operations repeated to give a further lift until the fuselage is in its correct position with the top longerons approximately level. At the points where the supporting trestles come into contact with the fuselage, it is advisable to introduce a thin packing of felt to prevent injury to the fuselage members while the weight is resting on the trestles. While the hydraulic jacks are being worked and the fuselage lifted, the supporting points on the fuselage should always be

followed up by packing on the supporting trestles to prevent damage to the longerons in the event of failure of the jacks. It must be remembered, too, that while the tail of the aeroplane is being raised the whole aircraft is pivoting about its wheel centres and as the tail goes up the front portion of the fuselage will go down. This means that as packing pieces are substituted to follow up the tail, the packing pieces under the front of the fuselage will have to be removed

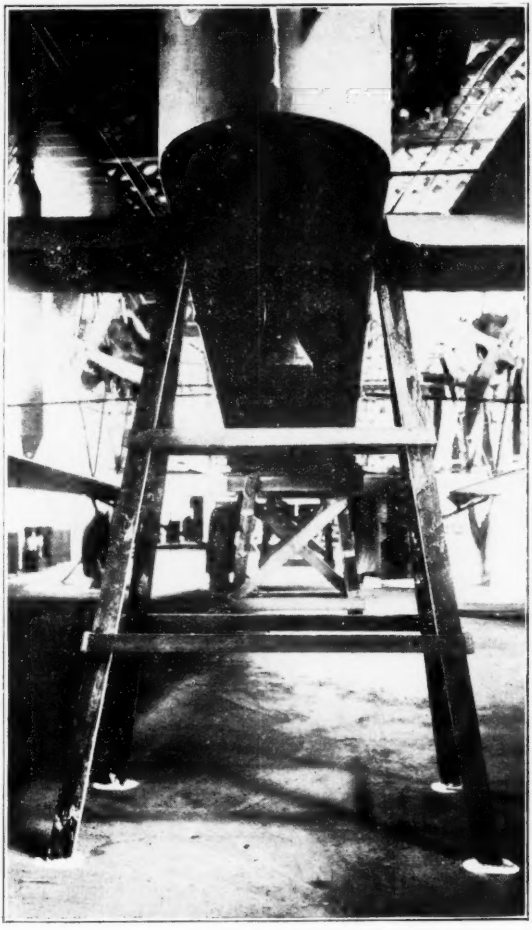


FIG. 5.—*Fuselage tail Trestle.*

and, if necessary, the trestle under the front portion taken away and a smaller one placed in position. From this also can be seen the necessity for securing the undercarriage wheels to prevent the aeroplane from rolling off the trestles. The fuselage is finally supported with its top longerons approximately level and the wedges on all the supporting trestles should be just gently tapped home until each trestle takes its appropriate share of the weight of the aeroplane. The front and tail supporting trestles in their actual positions under the aircraft are

shown in Figs. 4 and 5. In this position there will be a load of about 50lb. downwards on the tail skid, the point of balance of the aeroplane being under the bomb bay.

The next operation is No. 2 and consists of taking the load of the aircraft off the wheels of the undercarriages and so relieve the tyres of excess pressure and permit of deflation. To support the aeroplane in this position it is necessary to place packing blocks under the ends of the axles which project through the wheel hubs. It is impossible to lift by jacking the aeroplane at these points, as only about $\frac{3}{4}$in. of projecting axle end is available and this must be supported by the packing block. Two stiff wooden beams are therefore taken and placed across the centre section lower plane as closely as possible to the tops of the undercarriage struts and each undercarriage is treated separately, the aircraft being lifted first on one side and then on the other.

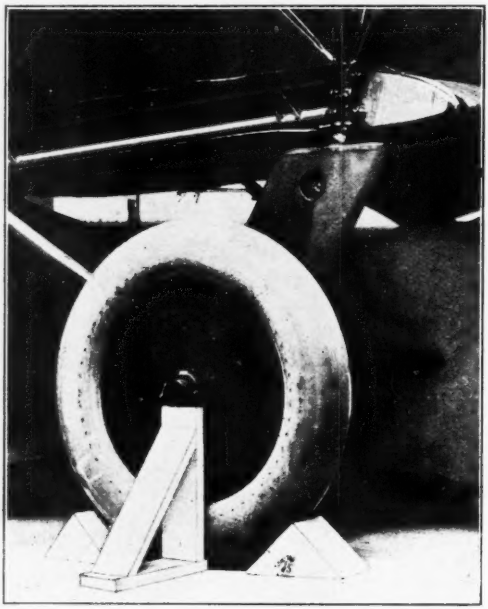


FIG. 6.—*Packing Supports for large Undercarriage.*

With the wooden cross beams in position, a hydraulic jack as used for lifting the fuselage is run under the beams and through wooden packing the weight of the aircraft is just taken by the jack. During this operation the specially constructed wooden packing blocks are placed on the floor near the ends of the undercarriage axles, and as soon as the undercarriage wheels clear the ground these packing blocks are inserted, one under each end of the axle which is being lifted. The whole machine is then gently lowered into position on these supports. The height of the packing blocks should be carefully gauged before they are placed in position and arranged so that, when in position, the wheels of the undercarriage may just clear the floor and be free to revolve. By repeating the process the other undercarriage can be supported in like manner and the complete packing for an undercarriage is shown in Fig. 6. After both undercarriages have been supported, V-shaped chocks should be placed before and behind each wheel.

It is well to note that as each undercarriage is being lifted separately, the whole machine is forced to rock slightly from one side to the other and in so doing each of the lower longerons of the fuselage have in turn to take a greater share of the weight of the machine than when the aircraft is in its normal position on the trestles. It is important, therefore, that undue lifting should be avoided during the operation. Also, supporting the undercarriages of the aircraft in this manner produces slackness in the front and intermediate fuselage trestles and makes it necessary, after the operation, to go round these trestle packings and readjust them so that they again are made to fulfil their proper functions. The small change in the level of the longerons which is occasioned by packing the undercarriage is immaterial for purposes of storage.

The aeroplane is now ready to have its main planes slung as mentioned in operation No. 3. For this purpose special standards are erected, one standard being placed in line with the lower ends of each pair of interplane struts. These standards may conveniently be constructed of wood, and they should be of such a height that they extend from the floor to about half way up the interplane struts. The load carried is not very great, but rigidity is necessary, so that

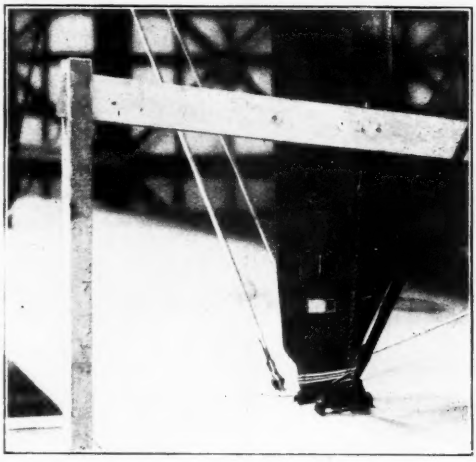


FIG. 7.—*Chain Sling for Main Planes.*

it is advisable to use upright members of about 3in. by 3in., and to construct the base so that the standards rest firmly on the floor. Across each pair of these standards, at their upper ends, is placed a wooden beam about 2in. by 3in., and has its ends let loosely into slots at the tops of the supporting standards so as to be easily fitted and yet unable to ride out of position when the load is placed on the cross beam. It will be found convenient to arrange the standards so that the cross beams can be adjusted to different heights for uses with aircraft of various sizes.

The weight of the main planes is carried on chain slings suspended below the cross beams, the lower ends of these slings coupling up to the bottom wiring plates of the interplane struts, and the upper end passing through the beam and having an ordinary screw attachment for vertical adjustment. The actual attachment of the lower end of the sling is shown in Fig. 7, from which it will be seen that a simple plate, bent at its end, is hooked round the anti-lift wire fitting; these plates being specially constructed to suit any particular

fitting. Two slings are attached to each cross beam and are coupled to the fittings at the lower ends of corresponding front and rear interplane struts, the amount of load carried being varied by the screw adjustment. In Fig. 8 one pair of main planes is shown thus supported.

Each sling of the pair attached to the same cross beam should be adjusted to take an equal load, as otherwise there will be a tendency to twist the main planes; also it must be remembered that by bad adjustment unequal loads are thrown on to the main plane supports. The condition to be aimed at is to have the weight of the main planes evenly distributed on each of the cross beams. By inserting springs of the same stiffness in each of the screw adjustments on the cross beams an indication of the load taken by each sling may be obtained by observing the compression of these springs, and in this way it is easier to see when each sling is taking its correct share of the load. When setting up these supporting devices the vertical standards should be placed about 4in. from

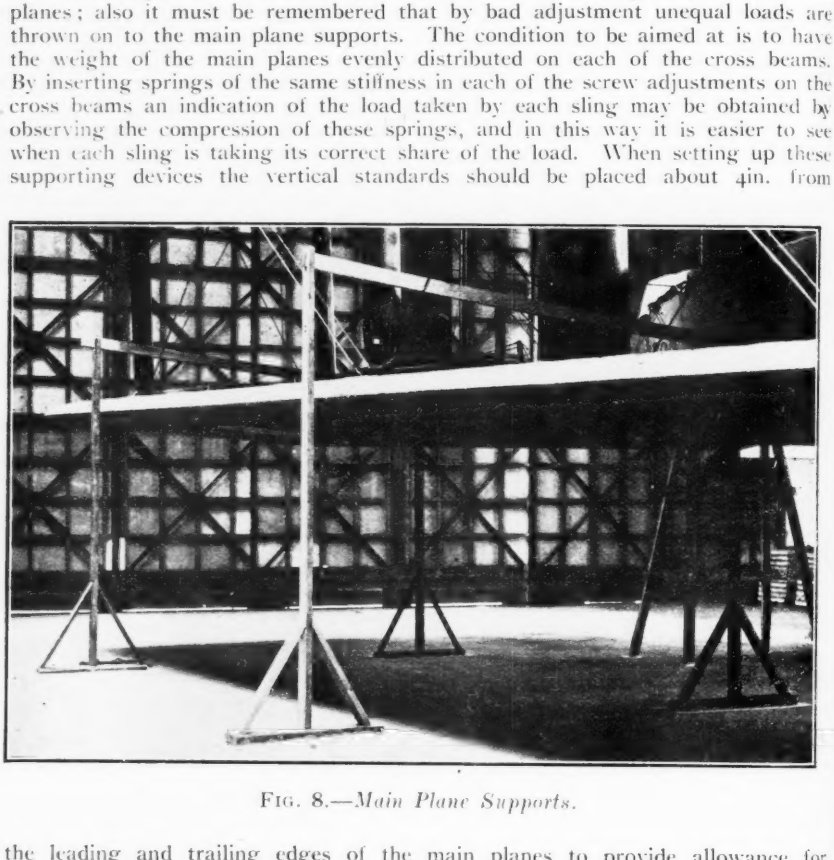


FIG. 8.—*Main Plane Supports.*

the leading and trailing edges of the main planes to provide allowance for possible bending of the standards when the load is taken on the cross beams, so that, if the standards happen to bend towards the wings, this clearance will prevent damage to the leading and trailing edges of the main planes. When the main planes are properly slung, the hinge joints on the centre section rear spars are relieved of a substantial amount of the weight of the planes, so that they are not so liable to be strained during storage, and the main planes are prevented from developing a permanent sag.

Operation No. 4 consists of securing the ailerons, elevators and rudders in their respective normal positions. By this means the freedom of these surfaces is limited and acts as a precaution against their being strained either by flapping in the wind, or by being forced beyond their normal limit of travel by other external means. When the aeroplane is stored with its main planes folded, the control cables from the control column to the ailerons are dis-

connected, so that the normal restraint, which could be placed upon the movement of the ailerons by locking the control column, does not appear, making the fixing of the locking devices as described below essential for holding the ailerons in their mid position. The elevators, however, remain connected to the control column, and as arrangements are made in the pilot's cockpit for locking the control column in its central position this means that the movement of the elevators is thereby limited. The attachment of a locking device to the elevators themselves is added as a further precaution against damage to the control system. For similar reasons the rudders are locked firstly on the rudder surfaces themselves and secondly through the control cables to the locked rudder bar. In most cases the control surfaces can be locked by two thin laths placed one on each side of the movable surface and clamped, handtight, to the corresponding fixed surfaces. This will give all the restraint required, but care should be taken not to damage the fabric by undue clamping.

It is next necessary, according to operation No. 5, to empty all petrol and oil tanks, and to drain the water system. In dealing with the petrol and oil, the contents of the tanks, although not to be used again for flight purposes, should be retained and used as a secondary supply. The petrol may conveniently be used for cleaning purposes or to supply ground power units, and lubricating oil, if the aircraft has not been a long time in the air, may first be filtered and then placed in store for subsequent use for ground purposes.

If castor oil has been used in the lubrication system particular care must be exercised to see that it is all thoroughly removed from the engines. This is necessary as it has been found that this kind of oil is capable of taking up moisture, and if allowed to remain stagnant for any length of time will lead to corrosion of the parts with which it is in contact. Other kinds of lubricating oil are known to retain moisture, but to a lesser extent; it may be taken, therefore, that lubricating oil should always be totally removed from the system, and particularly from the engine, before storage is commenced. In the case of water-cooled engines, the water must be drained off. When the respective systems have been emptied, the main tanks, filters and other important points may be cleaned as directed in later operations.

Considering now the operation No. 6, which directs that the engines should be cleaned down. For this purpose the outside parts of the engine are first wiped over with paraffin and petrol, the latter being conveniently some of that obtained when emptying the tanks during operation No. 5. After the removal of all dirt and loose oil the bright metal parts should be covered with a suitable anti-rust preparation. When applying these protectives in the solid state it has been found that the application, if not carefully done, may consume more grease than is really necessary, as the small spaces between the parts of the engine become filled and the open surfaces coated irregularly with an undue thickness of protective. Further, some parts may not be completely covered, thus defeating the object of the operation. It is known also that if rusting is commenced on a piece of metal, the oxidation may spread to adjacent parts, even though these parts be covered with protective preparation. To overcome these drawbacks, the anti-rust preparation should first be melted down so that it can be applied to the parts of the engine with a brush. This method leads to a much more efficient distribution of the grease, and the whole operation may be carried out in far less time than when the grease is applied in its solid state. When melting the grease only just sufficient heat should be used to make it run freely, as excessive heating may change the properties of the grease and render it less efficient as an anti-rust protective.

For this and other operations on the engines of large aircraft, a special scaffolding may be erected, which enables the men to obtain access to all parts

of the engine and to work in a convenient position. A general view of such a scaffolding may be seen in Fig. 9, and any similar erection may be used.

The next operation, No. 7, provides for the removal of the magnetos. These important parts are susceptible to the effects of moisture and require to be kept dry. After removal from the engine, the magnetos are usually labelled to associate them with a particular engine and then cleaned and stored in a manner to be described later.

Continuing with the engines and passing to operation No. 8, the throttle and magneto control should be cleaned and greased so as to ensure that they

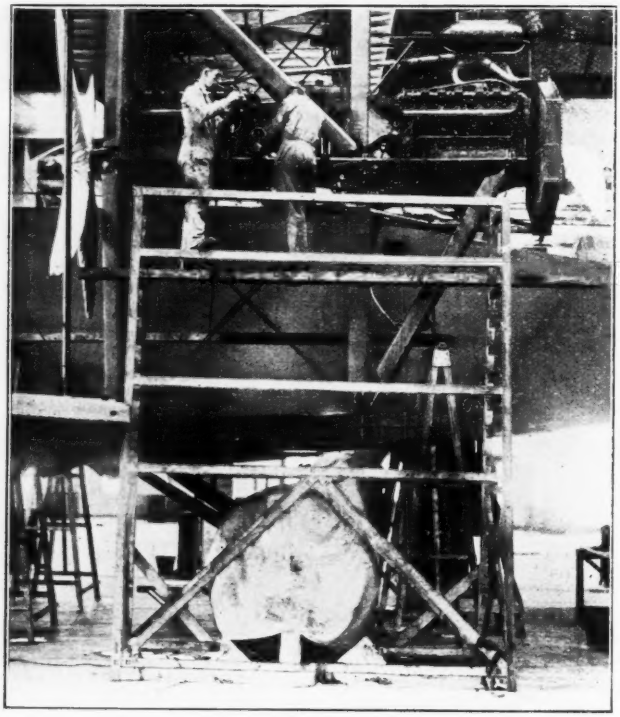


FIG. 9.—*Engine Scaffolding.*

will work smoothly. In the type of aeroplane under consideration, these controls are built up of hinged rods and are positive controls; the system necessarily contains a number of hinged joints which connect various portions of the rods, and these joints should be lubricated and overhauled for possible defects.

Next overhaul the engine valve gear, at the same time cleaning the springs and greasing the valve guides and stems where possible. The engine is not dismantled for this operation, which must be considered to apply to the external portions only. In this case the protective grease may better be applied in the solid state.

Proceeding to operation No. 10, the carburettors should then be dismantled and cleaned. For this purpose they are first taken off the engine, and while the cleaning is in progress the apertures leading to the induction system should

be closed either by a fabric covering being placed over the holes, or by lightly plugging the induction apertures. In this way dirt may be prevented from getting into the engine, and while the carburettors are removed, the induction apertures should not be uncovered for any other operations which are being carried out on the engine.

After the carburettors have been cleaned and are re-assembled, they should be replaced in their position on the engine; at the same time control rods should be connected up and the whole system tested through to see that it is working satisfactorily. This operation practically completes all that is required on the engines, and it remains now to ensure that, having once cleaned the engine down, no dirt or other undesirable matter can enter and so cause a repetition of the work.

Operation No. 11 is designed to this end, and it entails covering the exhaust manifold and engine breathers to exclude dirt. For this purpose it is customary to use fabric which, when cut to suitable use, may be secured in position by either wire or balloon cord. It is common practice to remove all the plugs from the cylinders, and when this is done the plug holes should be filled temporarily with close fitting pieces of wood.

Before leaving the engine operation No. 12 should be carried out and the engine covered completely by a large piece of fabric specially shaped for this purpose, a pair of engines with these covers in position being shown in Fig. 10. Covers of a similar material are also made and placed over each of the blades of the airscrews.

Although the engines have been previously drained there is usually a small quantity of oil which remains and finally drips from the engine. To prevent this oil from falling on to other parts of the aircraft, fabric or metal drip trays are hung one under each engine. These trays may be slung in any convenient manner and should extend along the whole length of the engine.

The next operation, No. 13, calls for the cleaning of the main planes under the engines. While the engines are running a certain quantity of oil oozes out and finally collects under the crankcase and drops on to the fabric of the main planes. With a well varnished dope no injurious effects can occur, but the protective coating on the fabric cannot always be relied upon to resist the oil, and troublesome results may occur if the dope film fabric is cracked or has been incorrectly applied. This oil may be cleaned off as described later; no hard rubbing or scraping of the fabric is desirable or necessary, as it is required only to remove the surplus oil and dirt, and care must be taken not to damage the dope film or the surface of the fabric.

The controls and controlling surfaces of the aircraft should next receive attention under operation No. 14. The control cables to the ailerons are necessarily disconnected when the aeroplane is folded, but the control cables for the other surfaces remain intact. In each case a cable run from the pilot's control wheel should be followed through to its respective controlling surface, and where these cables pass over pulleys or through fairleads a careful inspection should be made for cable fraying or other weaknesses; it is unusual for a cable to develop weakness at other points. If any cable is found to be inefficient, it should be plainly marked so that it may be replaced before the aeroplane is next taken into the air. All pulleys and fairleads should be greased, quick release fittings, if such are fitted to the cables, should be tried and cable splices wiped over and inspected.

Continuing to operation No. 15, this directs the removal of the wheels and the cleaning of the hubs and axles. It will be remembered that operation No. 2 arranged for the wheels to be lifted from the ground and to be held in that position by specially constructed packing pieces under the ends of the axles; before the wheels can be removed, therefore, it will be necessary to find another

temporary point of support for the undercarriage, so that the outside packing blocks may be removed and the wheels drawn off the axles. This provisional packing for the undercarriage may conveniently be placed under the axle and immediately behind each wheel, and the load taken off the outer packing pieces by jacking the undercarriage through wooden beams placed across the lower centre section as near as possible to the tops of the undercarriage struts. In this way the load may just be removed from the outside packing and lowered again on to the packing on the inside of the wheel. This enables the wheel to clear the ground, and after the removal of the retaining pin at the end of the axle, it may be withdrawn. When removed, the wheel may be cleaned down and the air pressure in the tyre reduced to prevent fatigue of the rubber. The axle end may be cleaned and coated with a fresh supply of grease lubricant. The wheel is then replaced on the axle and the load again taken by the jack, so that the provisional packing may be removed and the packing bracket inserted under the axle end. This operation is then repeated on each wheel in turn. If a faulty tyre appears, it will be found convenient during this operation to provide a replacement from store. When the work on both undercarriages has been finished, each wheel and spring shock absorber should be protected by a suitable waterproof cover, as shown in Fig. 10, which may be fastened round the top of the shock absorber and arranged so that it completely covers the whole unit.

The next operation is No. 16, and entails the cleaning of all external bracing wires and cables. In this operation, it is not essential that streamline wires be polished, although this is sometimes done, but in any case, after the wires have been cleaned they should be covered with an anti-rust preparation. It is advisable also to apply this protective to cables where such occur. In the case of streamline wires, these may conveniently be cleaned by rubbing parallel to their length so as to avoid their being twisted. This operation also affords an opportunity for the examination of turnbuckles and locking devices, and to see that all these are securely attached, with the exception, of course, of bracings containing quick release fittings.

When working on aeroplanes of the size under consideration it is not possible to reach the top of the main plane bracing wires without the aid of a scaffolding. With the main planes folded and supported as described in operation No. 3 no extra weight must be placed upon them, and to give the desired access to the main plane bracing wires the scaffolding should consist of planking placed across and between the main planes, being supported on trestles of suitable height. By adjusting this platform to various heights the whole of the bracing wires can be reached. To deal with the bracing of the tail planes, another similar scaffolding is erected against these surfaces.

Some of the internal bracing wires of the aircraft may also be cleaned as they are accessible, but in normal usage they are not exposed to the weather, so that it is only necessary to give a superficial treatment. The internal bracing wires of the fuselage are the principal ones which fall into this category, and in passing down inside the fuselage to carry out the work, care should be taken not to damage the fabric or cross struts. The operation may be facilitated by placing light boards along the tops of the bottom cross struts and by working from these boards.

Operation No. 17 completes the work necessary for storage of the complete aircraft, and directs that all fabric surfaces should be cleaned down. It will be found that some parts of the fabric become splashed with oil, especially near the engines, and others, such as the under surfaces of the lower main planes, may be coated with mud. The removal of oil from doped fabric has already been mentioned, but it remains to be added that the effect of oil is to increase the weight of the plane and to cause slight slackening of the fabric. On the type of oil used will depend the method used for its removal. In the case of vacuum

oil, this should be treated with soft soap and water and afterwards wiped down with benzol. With castor oil, which has a tendency to penetrate through the varnish and dope, the removal is more difficult; it can, however, be treated successfully by the use of soap and water, provided this treatment is applied before penetration of the oil to the fabric has had time to develop. Other cleaning agents such as petrol and alcohol may be used, and in the absence of benzol, petrol may be substituted. The soap and water dressing may conveniently be applied with a soft brush, and the other liquids with a pad of cotton waste wrapped in calico. It should be remembered that the action of petrol during cleaning is to remove the varnish from the dope film so that after such an operation the film is exposed and liable to crack and to lose its waterproof qualities. The petrol should therefore be used sparingly and only applied to the parts immediately concerned.

In the removal of the mud which may be thrown on to lower main planes by the wheels, it is not advisable to use any rubbing action, especially if the mud has had time to solidify. Rubbing this dirt under these conditions would lead to a considerable injury to the dope film and destroy all its protective qualities. As a preliminary treatment, therefore, the removal should first be effected by a water jet, and when most of the mud has been washed away, the small amount remaining will be so softened that washing with soap and water may be carried out without injury to the plane. It is obvious that continual cleaning by any liquids of one part of the fabric will eventually lead to the destruction of the dope film, and in places where the dope is found to be cracked by previous cleaning processes, these parts should be carefully treated so as not to aggravate the trouble, thereby allowing oil and water direct access to the bare fabric. Parts of the aircraft which do not suffer from the effects of oil or mud may be just lightly wiped over for the removal of dust or water. The operation of cleaning the whole aircraft affords an opportunity for the detection of such internal defects as a damaged rib or trailing edge.

The foregoing 21 operations may be taken as representing roughly the complete sequence which is required for the storage of a large type of aeroplane, such as is shown in Fig. 10. For obvious reasons this cannot be applied to every type of aircraft indiscriminately, but the fundamental principles will remain the same, modification being introduced to suit any given set of conditions.

Where shed spaces permit and when it is probable that the aircraft will not be in store for a long time, it will be found an advantage to store the complete aeroplane with its wings spread. From a point of view of storage space this is, of course, not so efficient a method as with the wings folded, but it is convenient when the aircraft has to be placed in commission on short notice. A typical illustration of an aeroplane thus stored is given in Fig. 2, which shows that the fuselage is supported on trestles with its top longerons horizontal as before. The undercarriages are lifted and supported with their wheels just clear of the ground, and fore and aft packing blocks placed in position. The main planes under these conditions require no additional supports, and their weight is taken up by the anti-lift bracing wires. These conditions of short duration storage do not call for the removal of the instruments, and in a properly constructed shed the engines need not be covered.

Seaplanes.

In the case of a large boat or float seaplane much of the detail for storage will remain the same as for an aeroplane, with, of course, special treatment added for the hull of a boat seaplane.

As outlined previously, a seaplane falling into the classification of a large type, may be taken typically as the " F " type flying boat. The size of this

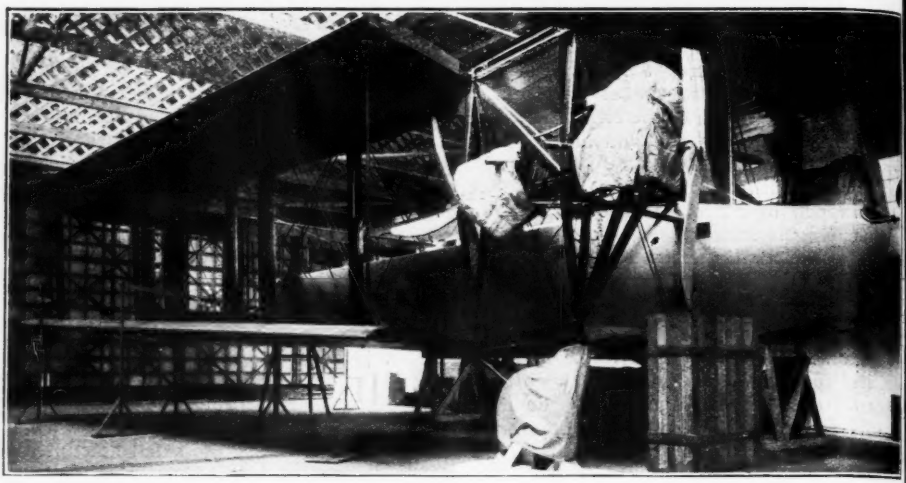


FIG. 10.—*A large Aeroplane in Store.*

type of aircraft is approximately, height 17ft. 6in., span 95ft. 8in., and overall length 46ft. 3in.

Assuming the seaplane is placed in its correct position in the storage shed, the shape of the hull does not permit of its being lowered directly on to the floor, but it should be accommodated in a strong wooden cradle built to fit its under side. In this way the weight of the machine is distributed and damage to the hull avoided. For prolonged storage the aircraft is therefore transferred from its transporting or beach trolley to the storage cradle, while for shorter periods of storage it may remain on its trolley. A boat seaplane supported on its trolley is shown in Fig. 11, this position being equivalent to that of the large

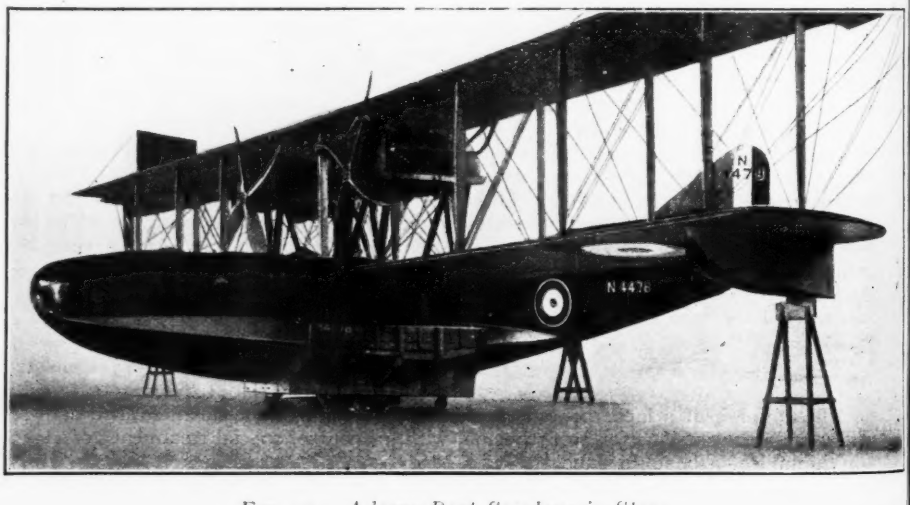


FIG. 11.—*A large Boat Seaplane in Store.*

aeroplane with its fuselage on the supporting trestles. The variation in the treatment for storage of a seaplane as compared with an aeroplane is chiefly in the operations on the hull.

With a seaplane taken directly from the water and placed in the storage shed, it is firstly necessary to remove all surplus water from the hull and to wipe over the entire hull structure.

With the hull resting in its cradle on the floor of the shed, the weight of the main planes can be taken up in a manner similar to that employed for a large aeroplane, that is, either by placing trestles in convenient positions near the wing tips and packing up under the wing tip floats or by placing standards in line with the interplane struts and slinging the bottom planes. When the former is done care should be taken to place the trestles only under the keel of the floats. With the hull resting firmly in its cradle, the main planes will take up a definite attitude, and in taking the weight of the main planes care should be exercised not to overpack on the trestle supports, which not only will tend to rock the hull in its cradle, but also will subject the main planes to stresses equally bad as though they were unsupported. With the whole aircraft thus supported, the various operations prior to storage may proceed, and will consist in the main of those detailed for a large type of aeroplane. It is, therefore, unnecessary to reiterate this detail.

The most important feature is the cleaning down of the hull and superstructure, including the external bracing wires. Sea water has a very actively corrosive effect upon steel and other metals, so that the necessity for removing all surplus water is accentuated. The tendency of modern practice is to provide permanent protection of the external bracing wires and other exposed metal parts by treating them before they are embodied in the machine. Galvanising of steel parts forms a protection against the corrosive effects of sea water, but even when this is done, it is necessary to remove all water which may have collected on the parts thus treated. For similar reasons the aluminium fittings are sometimes treated with a special type of varnish consisting of one part of velure varnish and two parts of turpentine. In cases where such treatment has not been given to the metal parts, such as uncovered steel struts, the removal of surplus water should be followed by a liberal application of mineral jelly. The conditions of the hull of being alternately wet and dry are detrimental to its efficient storage, and for this purpose provision should be made to keep the hull watertight. Various methods of doing this are possible, one being the application of damp matting to the hull structure. This matting should be redamped as frequently as may be necessary, having regard to the local conditions of the atmosphere, and should not be placed near metal parts, but only over the wooden parts of the hull which normally come in contact with the water. Shrinking of the hull structure is thereby avoided, and the joints maintained watertight. A further method will be described later, when dealing with hulls as components.

The wing tip floats being of three-ply construction and their functions also producing alternate wet and dry conditions, similar treatment should be given as for hulls. For prolonged storage the floats may be removed from the main planes, and in this case they will be dealt with as separate components as described later. If they remain on the seaplane during storage they should be maintained externally damp to prevent the joints from opening.

The main fabric surfaces should be cleaned down and oil which may have dripped from the engine removed as described previously.

The detail required for the engines follows on the same lines as for an aeroplane, but having regard to the possibility of sea water entering the engine parts, particular care is necessary in cleaning down these parts, and the following application of mineral jelly should be made as thorough as possible.

Airscrews are protected in the usual way, by enclosing their blades in fabric bags which are connected together at the boss of the airscrew, the blades having previously been wiped over.

SMALL TYPES OF AIRCRAFT.

In passing to the storage of small aircraft a new set of conditions are encountered, and it does not follow that the whole of the operations described for the storage of large aircraft may be produced as it were in miniature and applied to smaller machines. However, many of the general principles remain the same, but it should be remembered that although the weights of the parts of these aircraft may themselves be much smaller, yet the much lighter construction which goes with it combines to produce similar stresses in the parts and indiscriminate storage may produce considerable depreciation and inefficiency.

As in previous cases, the methods of storage have been demonstrated by the considerations of an actual type of aeroplane and seaplane, so in this case the procedure will be associated with definite representative types of aircraft which fall into this category.

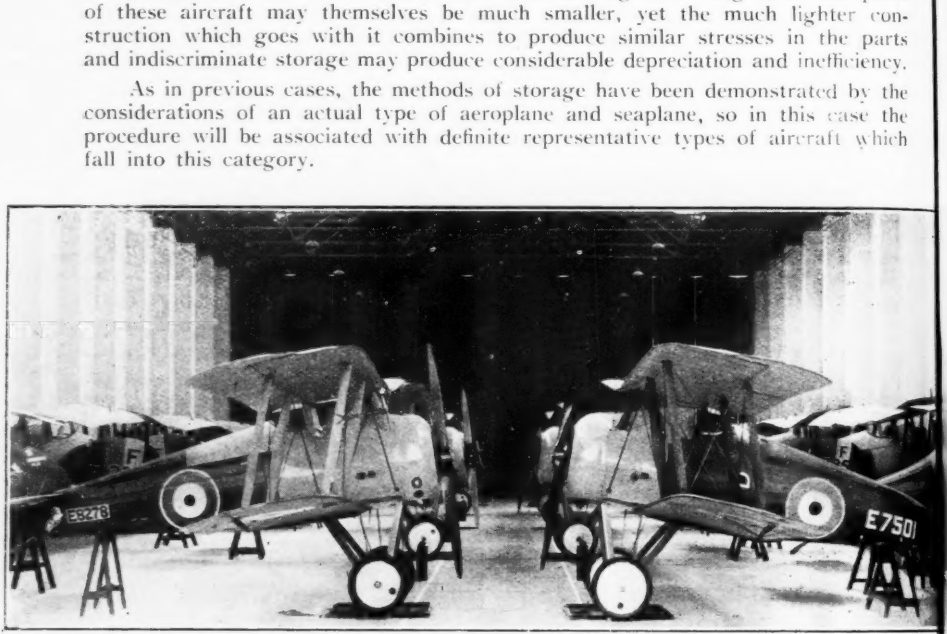


FIG. 12.—*Small Aeroplanes in Store.*

Aeroplanes.

To deal firstly with an aeroplane, it is proposed to take as an example the Sopwith Snipe, which has a span of 31ft. 1in., an overall length of 19ft. 10in., and a height with the fuselage on trestles of 8ft. 9in. It is fitted with a 200 h.p. B.R.2 engine, and is a single seater aeroplane.

It is not usual to construct special storage sheds for each type of aircraft, so that the buildings have to be adapted to house either large or small types of aircraft. Again there is usually a greater number of small aircraft than large ones in use, so that when housing the smaller types regard must be had to efficiency of accommodation, and simply because a storage shed is comparatively large is no reason for the inefficient use of floor space.

Considering now the storage of Sopwith Snipe aeroplanes. Firstly, as complete aircraft, they should be carefully arranged in the shed, and then each aeroplane should be supported in the manner about to be described. One such arrangement is indicated in Fig. 12, but this must not be taken as the only

scheme which may be used. When the aeroplane has been placed in its appointed position, the tail should be raised so that the intermediate supporting point of the fuselage, as marked by an arrow, rests on a trestle about 30in. high. The undercarriage is now supported by packing blocks placed under the axle just behind each wheel and so that the wheels are clear of the ground. To collect any oil which may fall from the engine a drip tray containing sand should be placed between the wheels and under the engine. These operations complete all that is necessary for the actual supporting of the aeroplane; it then remains to go over the machine and perform similar operations to those described in Nos. 5, 6, 8, 9, 10, 14, 15, 16, and 17 relating to the storage of large aircraft.

The parts of a small aircraft are more accessible than those of large types, and with the exception of the upper main planes, most parts of the aircraft can be reached from the ground.

After cleaning down the whole aircraft the air pressure should be released from the tyres. The engine should next receive attention, and be cleaned externally, with a final coating of an anti-rust preparation on all outside parts. It will be found convenient to apply this protective in the liquid state as described previously. As in this type of aircraft a metal cowling is arranged to cover the engine, the protection afforded by this means is usually relied upon for the exclusion of dirt when the aircraft is stored, but in order to supplement the cowling and for use during prolonged storage, an additional covering of waterproofed fabric should be placed over the front of the aircraft so as to cover entirely the cowling in the engine. This cover should be drawn up tightly round the propeller boss and laced closely under the engine.

In an alternative method of storage of a small aircraft, partial dismantling is resorted to. The aircraft under these conditions is usually dismantled into the fuselage complete with undercarriage, engine, airscrew, fin and rudder, the main planes, the tail plane, and the elevators. With this method only a small amount of work is required to re-erect the machine if it is required from store on short notice. Both this and the former method of storage, however, are not used for the periods of storage longer than approximately two months; greater periods than this call for complete dismantling of the aircraft. When erected, the wings of any aircraft are necessarily parts which occupy a large portion of shed space, and their removal for separate storage allows a greater number of aircraft to be stored in a shed of a given size.

For storage in the partly dismantled condition, the metal parts of the aircraft are all cleaned and greased before dismantling. Covers are then attached as required, usually over the engine and over the pilot's cockpit, the latter not being necessary when storing aircraft complete, owing to the short duration of storage. It is well that the main planes and tail plane, although removed from the fuselage, should be associated with their particular machine by storage references, which may be done either by written records with a system of numbering, or, as will be described later, by grouping them with the other adjuncts of the aircraft of which they are part. Reference to Fig. 13 will indicate one method by which partly dismantled aeroplanes may be stored, and shows the complete fuselages with their undercarriages, engines, fins and rudders fitted, and supported with their wheels off the ground. Each centre section plane rests against its respective fuselage. In this case, some of the weight having been removed, it is not found necessary to raise the rear end of the fuselage on to a trestle, and it is consequently seen resting with its tail skid on the ground. In passing it may be mentioned that the airscrews have from time to time to be turned to different positions, and this should be remembered when attaching the covering over the engine.

The storage of the main planes and tail planes of these aeroplanes will be described later.

The other method of storage, in which the components of each aircraft are grouped together, will now be considered. The scheme has been devised for compactness of storage and to avoid a number of clerical cross references for identification of the parts of an aircraft.

The aircraft is accordingly dismantled to the extent of removing the main planes and tail unit, leaving the fuselage fitted with undercarriage and engine. The whole components of one aircraft are then placed together, in as compact a form as possible in the storage shed, the general arrangement of such a scheme for the Parnall Panther being shown in Fig. 14. In planning out aircraft under this arrangement, the fuselage is first placed in position in the shed and has the wheels of its undercarriage supported just clear of the floor as in former cases, and its tail skid resting on the floor. The other components of the aircraft are then packed round the fuselage, which may conveniently be done by placing all

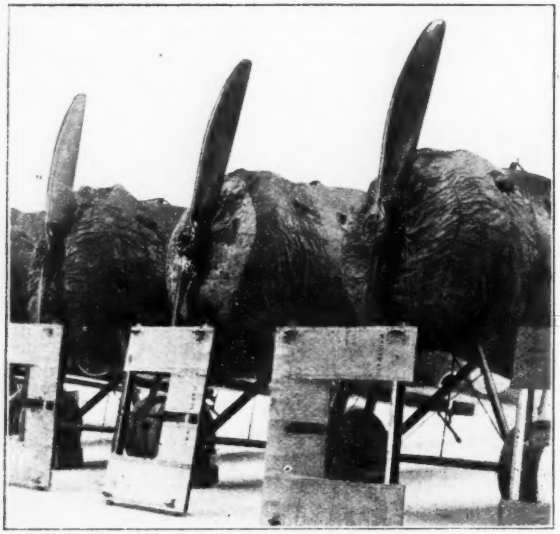


FIG. 13.—*Storage of small Aeroplanes partly dismantled.*

the interplane struts and wires on the floor under the fuselage, the centre section plane in front of the fuselage, the tail plane and elevators at the side of the fuselage near the tail end, the main planes in pairs down the respective sides of the fuselage and all other loose equipment in the cockpits. The airscrews for machines so stored are usually removed and stored separately. A detail view of D.H.9 aeroplanes stored in this way is shown in Fig. 15.

In storing aircraft in this manner there is a considerable possibility of damage being done if care is not exercised in the way the components are placed together, and it can be seen from Figs. 14 and 15 that the main planes and other fabric surfaces are the most liable to damage. Taking the case of the main planes, these can simply be left lying loosely against the fuselage, or alternatively they may be first fixed in cradles as shown in Fig. 15. Where possible also the leading edges should be protected, and if the main planes are accommodated in the cradles this protection is given, otherwise at certain points along the leading edges felt pads should be placed to carry the planes, and thereby raise them from the ground throughout their entire length. In

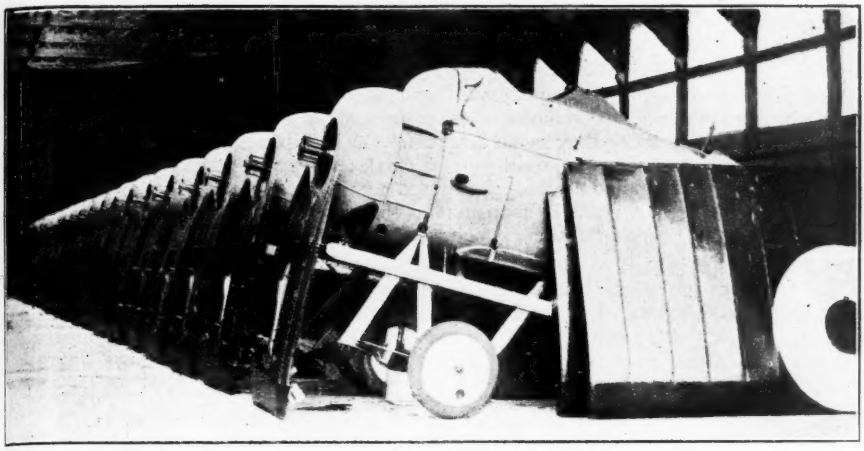


FIG. 14.—*Collective Storage of Parnall Panther.*

placing the main planes against the sides of the fuselage care should be taken to see that there is no prominent projection such as the lower centre section end rib, or other like fitting which may damage the planes; the weight of the planes is not great, but to rest them even lightly against the fuselage, so that they were bearing on one point of the fabric only, would probably involve injury to the plane. Again, it should be remembered that unless the main planes are supported throughout their entire length they will, after a time, be liable to permanent twist by the drooping of the unsupported portion. For these reasons, therefore, it is better to fix the main planes in a suitable frame and to

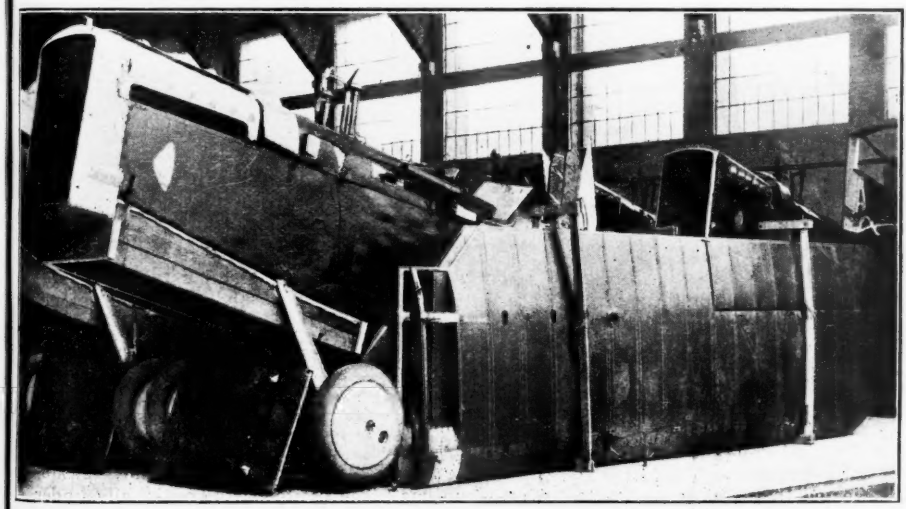


FIG. 15.—*Collective Storage of D.H.9; Positions of Components.*

stand the frames just clear of the fuselage. The smaller surfaces, such as the upper centre section, tail plane, elevators, are not so liable to twist, but they are equally liable to damage by puncturing of the fabric.

When leaning these components against the fuselage, that is, when the main planes are not accommodated in cradles, they should be inclined at such an angle as will ensure their remaining safely in that position. At a small angle to the vertical they may certainly be packed closer to the fuselage, but it is possible they may fall outwards if exposed to a draught of air or are inadvertently touched. This point is important in the case of centre section planes such as those of the Parnall Panther, which, containing petrol tanks and fittings, may be rendered useless by a fall.

In the case of those aeroplanes which are adjacent to a gangway, a clearance barrier should be placed around the outer components, that is, outside the main planes, so that these components are not damaged by traffic along the gangway.

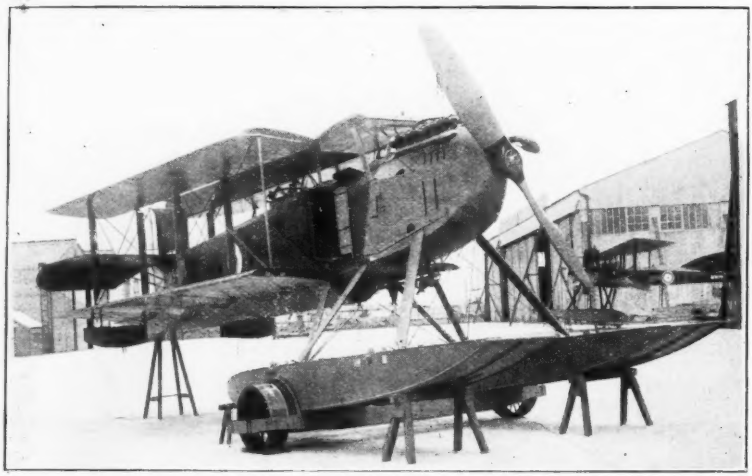


FIG. 16.—*Fairey Seaplane supported with Main Planes folded.*

This method of storage does not afford such convenient facilities for periodical inspection of the aircraft as the other methods described, but by suitable placing of the components, access may be gained to a fair proportion of the whole aircraft.

Seaplanes.

In the category of small aircraft there appear the smaller types of seaplanes. Most of these aircraft are, in construction, similar to a small aeroplane, but have substituted for the undercarriage a landing chassis composed of struts and watertight floats. In the main, therefore, the storage of a small seaplane must necessarily follow much on the same lines as that of an aeroplane of about the same size.

Apart from the features of design which are essential to a seaplane, there are the characteristics previously mentioned which call for special treatment for storage, namely, that whereas a land aircraft may not, apart from rain, be subjected to the effects of water, a seaplane has some of its parts continually under changing conditions of alternate wet and dry, and in windy weather it will be splashed with water practically over its entire surface, also the action of sea water is more detrimental to metal fittings than ordinary rain water, so that the protective

devices used on seaplanes should therefore be more efficient than those applied to aeroplanes.

Following on the lines of the previous notes, it is proposed to take a typical example of a small seaplane, and for this purpose the Fairey seaplane will be used. To enable a general idea to be obtained of this aircraft, it may be mentioned that it has overall dimensions of, span 46ft. 1in., length 36ft. 1in., height, with fuselage horizontal, 13ft. 1in. A crew of two is carried, and the main planes may be folded back along the fuselage. When on the water it is supported by two main floats, and the tail rests on another smaller float.

Being a small type of aircraft, it may be placed in store as a complete machine, and when so stored, the main floats may either be supported on a trolley or rest on battens on the floor of the shed; in both cases the fuselage will rest on a trestle placed under the tail float. The other parts of the aircraft are subject to the same usage as described for a Sopwith Snipe aeroplane. It will be unnecessary, therefore, to repeat the detail, and the considerations will be confined to those points which are peculiar to a float seaplane.

The seaplane is first located in an appropriate position in the storage shed, and to provide mobility for this operation the main floats are carried on a specially constructed trolley. This trolley, shown in Fig. 16, is built up of strong timberings, which form a framework 14ft. long and 3ft. wide, and is carried through an axle on two wheels. It is also used for transporting the seaplane to and from the water. In raising the aircraft from the ground on to the trolley, packing blocks of semi-circular section are used. The ends of the blocks are of semi-circular shape about 32in. in diameter, across which battens are attached. The diameters are boarded over to form a flat surface, and the length of the packing blocks is equal to the width across the main floats of the seaplane. To raise the aircraft on to the trolley, the tail is first lifted and one semi-circular packing block inserted with its flat top under the step of each main float, and with its circular portion on the ground. The tail is then lowered and the wheeled trolley pushed as far as possible under the front of the floats. The tail of the aircraft is now lifted again, and packing blocks placed between the semi-circular supports and the main floats, after which, by lowering the tail, the trolley may be pushed further under the main floats. This rocking operation is continued until the axle of the trolley is slightly in advance of the rear cross booms of the chassis, and in this position, with the aircraft horizontal, the weight will fall behind the axle of the trolley, so that a lift will have to be applied at the tail before the seaplane can be moved. In this particular type of seaplane, lifting handles are provided on each side of the tail float, and should be used for taking the weight at that point.

The seaplane having been placed on the trolley and moved to its correct position in the storage shed, it is necessary to reverse the order of the operations given above in order to lower the aircraft on to the floor of the shed. Before doing this some soft packing material should be placed on the floor so as to avoid damage to the main floats of the seaplane. When this operation is completed and a trestle placed under the tail end of the fuselage, the seaplane is in its correct attitude for storage.

For more compact storage the aircraft may be maintained in its complete condition, but will have its main planes folded. In this position the planes will lie along the fuselage as shown in Fig. 16.

Most of the features special to a float seaplane have now been covered; the remaining operations needed to complete the storage of such an aircraft will cover :—

(1) Cleaning and overhauling the engine.
(2) Emptying fuel, oil, and water tanks and systems.

(3) Locking movable control surfaces and controls.
(4) Cleaning down the whole aircraft.
(5) Applying anti-rust and other protective preparations to various parts of the aircraft.

In carrying out these operations, the tops of the main floats should not be used indiscriminately as platforms for access to the engine, as the floats are of comparatively frail construction. In fact, it may be said that in the case of aircraft of this type the main floats are the most vulnerable portion, and when damaged, render the whole aircraft unserviceable. Along the top of the main floats in seven places are fitted screwed inspection covers, which have air holes pierced in them to allow of proper distribution of internal pressure when the aircraft is in flight; these covers should be left open while the aircraft is in store, and at the same time it should be seen that the air holes are clear.

The last operation is the application of protective preparations to various exposed parts, and it is necessary, in the case of this type of aircraft, to concentrate on this work. In use, the main floats and tail float are subject to a liberal splashing of sea water, and it is essential that all this water be removed before any protective preparation is applied. The exposed metal parts of the chassis may conveniently be wiped over with oil after the water has been removed and preparatory to the application of the protective preparation. A similar treatment should be given to all lower parts of the aircraft, comprising the lower main planes and tail unit, and the possible inroads of sea water should not be forgotten when dealing with the engine and the upper parts of the aircraft.

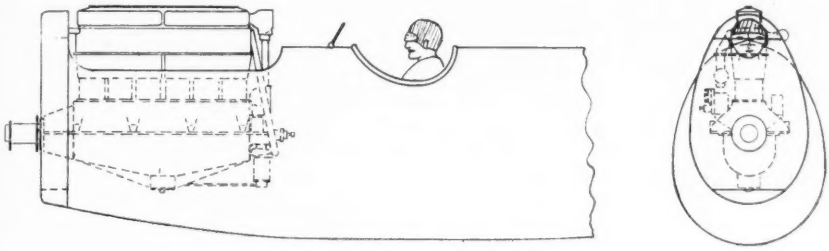
(To be continued.)

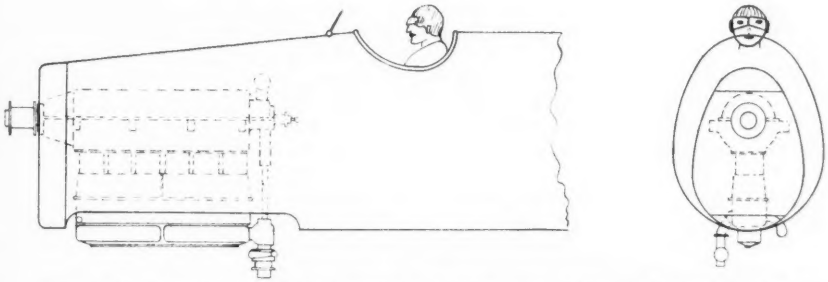
CORRESPONDENCE.

To the Editor of THE AËRONAUTICAL JOURNAL.

Dear Sir,—With regard to the interesting lecture on engine installation given by Brigadier-General Bagnall-Wild and reported in the April issue of the AËRONAUTICAL JOURNAL, it has long been a matter of surprise to the writer that more attention has not been paid by aircraft engine designers to the inverted engine.

Possibly the most important requirement of a fighting and reconnaissance machine is that it should allow the pilot the clearest possible range of vision. In the tractor type of aeroplane or seaplane, with engines as they are designed to-day, it is almost impossible to obtain a good view forward owing to the obstruction offered by the engine.





Some three years ago I had much pleasure, but, alas, little satisfaction in drawing the attention of the Air Ministry to the great advantages which would accrue, in the matter of vision, from the use of an inverted engine. I enclose some comparative drawings* which I then submitted. The inverted engine would do much to make possible the very desirable feature of a simple gravity feed petrol system which General Bagnall-Wild rightly advocates, whilst at the same time it would facilitate the leading away of the exhaust gases and lead to a greatly improved forward view.

There are several other advantages which aeroplane and seaplane designers will readily see, such as improved ground and water clearance for the propeller, etc.

Yours faithfully,

April 7th, 1922. H. O. SHORT.

* One set only printed.—EDITOR.

OBITUARY.

SIR WALTER RALEIGH.

Aviation has suffered an irreparable loss in the death of Sir Walter Alexander Raleigh, the official historian of the War in the Air.

When the Royal Air Force became a separate arm of the forces of the Crown, taking rank with the Navy and Army, its tradition was already safe. But tradition is a great thing, and to exert its proper influence on a service it must be recorded and handed down from generation to generation to inspire them with accounts, fittingly told, of deeds of heroism and devotion to duty; and in the case of the Air Service of battles with the elements as well as with enemies—a story peculiarly its own, dealing with its own special trials—a story of the chivalry of the air.

The question as to whether there should be a separate Air Force is one which still stirs deep feeling, but this question has already been settled. The Royal Air Force has outgrown its pupilage to the older services and is now one of their partners. When it was officially decided that the history of the War in the Air was to be written, the Royal Air Force found its destined historian in Sir Walter Raleigh. During a discussion as to the form this history should take, he exclaimed, "It is a chance of a lifetime."

Before attempting his task Sir Walter decided to see something of the War in the Air. He proceeded to France on the 14th August, 1918, and returned on the 8th September. During that fortnight he was taken over the various headquarters and depots and saw what he could of the work of the Air Force under war conditions and made a keen study of the personnel. He was flown over parts of the front. Writing home on the 26th August, 1918, he says: "Now I am with a fighting squadron (for the first time) and I hope to get into a Bristol Fighter. The Camel and Snipe are not for me. I got right up to the front to see artillery working with aeroplanes, and I am on the way to understand sound-ranging, which is a wonder. Also, I am picking up the Ac Beer Cee Don language. . . . Where I am now we are bombed every suitable night."

He started to write the history of the War in the Air at the beginning of 1919. Its beginnings caused him considerable anxiety. He found official records scanty and bare. He planned and replanned the book. At first he only intended to devote a chapter or two to the pre-war period, but he soon realised that if the story was to be worthily told the history of the conquest of the air must first be dealt with. This involved considerable labour. A host of technical details had to be carefully studied. Not a fact would he accept without having previously mastered its significance. If he were told that the upper surface of the plane contributes most lift he would want to know why. On being informed that wireless reception in an aeroplane with the engine running at full power was first accomplished in September, 1913, he wanted to know by what special means, and before he left the subject he had made a study of wireless itself. The reported incident of an R.E.8 aeroplane flying itself for two hours with a dead pilot and observer led him into a detailed study of aeroplane stability and so on.

It is fortunate for aviation that Sir Walter, who only intended to summarise the early history, found himself drawn more and more into it with the result that about half of the first volume of the official history of the War in the Air is a classic on the art of flight itself. Aviation could have found no better friend,

no more enthusiastic student and no one more competent to tell the stirring story of the conquest of the air.

The following extract from a letter which he wrote at the very outset of his last great task is typical of what he felt to be his theme :—

" The humblest flier who went and strafed a Boche and got done in is not going to be sacrificed or even subordinated to the star performers. Every V.C. shall be clearly told that men who deserved it as well or better than he did are forgotten, in large numbers, because they faced certain death without witnesses. The hero of the book is chosen and is the Air, not the stars."

After finishing his first volume he decided to carry out his visit to the eastern theatres of war—a visit which was originally intended to follow closely after his visit to France in August, 1918, but the Armistice intervened and the visit was deferred. The dangers of such a visit to his health were pointed out to him, but this only made him more determined than ever. It was for his book, the story of the Royal Air Force, and he would allow no real or imaginary danger to stand in his way. On March 16th, 1922, he left London for Port Said, travelling via Marseilles. He proceeded to Jerusalem and then to Amman. From Amman he was being flown to Basra when a forced landing had to be made in the desert owing to one of the three aeroplanes of the flight breaking down. A halt of four days was made under bad weather conditions. On arrival at Baghdad all was not well with Sir Walter Raleigh. He was next flown to Mosul. Here he contracted fever, for which he was treated, and he was advised to await proper recovery. But he wanted to get back to his work at Oxford so he returned to England while suffering from fever. He came back on the 25th April and not many days afterwards the fever had him in its grip. Typhoid was diagnosed and peritonitis supervened. He was operated on on the night of Thursday, 11th May. Although he rallied after the operation he died early on Saturday morning, the 13th May.

Sir Walter Raleigh had attained great distinction as an authority on English literature, as an eminent critic and as a pre-eminent stylist, before he took up with aeronautics. But it is the opinion of the author of this brief tribute that his fame will ultimately rest on the last literary achievement of his great life—the history of flight and the British Air Service. Although he only lived to complete one volume his services to aviation are outstanding. No man was better fitted to tell the story, in so far as words can express it, of the mastery of the air. No other man of mature years could have shown such youthful enthusiasm, such a wonderful grip of the temper of the air.

The author was only privileged to know Sir Walter Raleigh during the past three years in connection with the history of the War in the Air and does not feel competent to discuss his life and influences on literature. The object of these notes was to place on record some account of his work and devotion to aviation and the Air Service.

Walter Alexander Raleigh was born in 1861. His father was Dr. Alexander Raleigh, the Scottish Congregationalist divine. He was educated at University College, London, and King's College, Cambridge. At the age of twenty-three he was appointed professor of English literature at the Chief College, Aligarh. There he remained for two years, but for reasons of health he returned to England. His next appointment was assistant to Sir Adolphus Ward at Owen's College, Manchester. A year later, in 1890, he succeeded Mr. A. C. Bradley as Professor of English at Liverpool University. This post he held for ten years and during that period he earned a niche in the temple of fame by bringing out his books, " The English Novel " in 1894, " Louis Stevenson ; an Essay " in 1895, " Style " in 1897 and " Milton " in 1900.

In 1900 Walter Raleigh was appointed to the English chair at Glasgow, again in succession to Mr. A. C. Bradley, and there he remained four years. During

this period he published "Wordsworth" in 1903 and "The English Voyagers" in the following year. In 1904 he was appointed to the new chair of English literature at Oxford. In 1907 he produced his "Shakespeare" and in 1910 "Six Essays on Johnson." He was knighted in 1911 and became a Fellow of Merton College, Oxford, in 1914.

During the war he was the moving spirit in getting good literature supplied to the troops by means of broadsheets. He firmly believed that English literature was the highest possible expression of freedom and in this he was right. In 1917 he produced his book "Romance."

In addition to writing some stirring appeals during the war, he edited the "Oxford Roll of Honour" after the war. Perhaps the most enjoyable years of his life were the last, when he was busy with the theme which fascinated and held the whole of his being. Never were his lectures so inspired as when his lecture theatre was crowded with the post-war students, many of whom were war veterans.

Concerning the history of the War in the Air, he said:—

"Some authors seem to seek fame; I shall be satisfied with forgiveness."

In this one line Sir Walter wrote his own obituary.

He was married in 1890 to Lucie Gertrude, the daughter of Mr. Mason Jackson. He leaves three sons and one daughter.

REVIEWS.

Notes and Examples on the Theory of Heat and Heat Engines. By John Case, M.A.

Professor Case has set out to write a book which should not be an exhaustive text-book, "but rather a companion to lectures, to help the student to see at a glance the important points of the subject, and to assist him with his revision for examinations." In this aim he has succeeded admirably and has produced at the same time a little book which will prove a handy work of reference to engineers. The subject matter is well chosen and the text clearly and concisely written. Any student who works successfully through the many typical problems given will have a very good initial knowledge of the application of the principles of thermodynamics to engineering.

Cours Pratique d'Aviation. By Capitaine Jambier and Lt. de Vaisseau J. Amet, Pilotes aviateurs. 1922.

The authors of this little book have undoubtedly succeeded in their aim, in treating the whole subject of aeronautics in a popular manner, avoiding wherever possible technicalities likely to confuse the youthful enthusiast. Some of the explanations given appear to be almost too simple; for instance, the treatment of stability is such as to leave the impression with the non-technical reader that the subject is no more complex than the explanation given. It should certainly arouse interest in the science of aeronautics, in the hands of any student, but whether sufficient space is devoted to the care taken in design, construction and testing to inspire confidence in a would-be aircraft passenger (as is hoped in the preface) is somewhat doubtful.

In treating the subject in a general manner the authors have avoided detail, but the classification of aerofoils into classes of nationality, for instance, as is done on page 7, rather than into types showing different characteristics, goes, it is felt, rather to the other extreme. The authors are to be congratulated, however, on the achievement of their main object in putting before the public a popular treatise on aviation.

La Photographie Aérienne. By André H. Carlier.

This work is one that should be studied by all interested in aerial photography, both past and present.

M. Carlier has dealt with the subject in a very comprehensive way; in fact, if a fault can be found, it is that the book is too comprehensive, as it starts with the theory of photography in the air, deals with restitution, goes into the subject of most of the cameras that were used by all the armies in the war, describes the organisation in the French Army of their photographic section, and then winds up in a very full way with the interpretation of aerial photography from the point of view of the general staff. Such things as stereo photography are also dealt with, and a table of separations, which is useful, is incorporated.

M. Carlier, very rightly from his point of view, imagines that the system and apparatus used by the French was the last word in the art, but with that I do not cordially agree. Such things as their standard changing box made by Gaumont, which were used to the end, were not very satisfactory articles, and although such cameras as the De Ram are illustrated, they were not functioning

in any quantity even at the end of the war, so that an opinion is difficult as to their practicability even now for use in the field.

Our own system of photography was based on supplying an apparatus which was fool-proof and of which the pilot or observer had little knowledge except to pull definite levers at definite times. The French effort was more individual, and I have even seen some of their cameras that had to be focussed! Provided suitable operators could be found some of their individual work was very brilliant, but the standard of work must be reckoned by the least successful, not by the most successful.

There is little mention of the long distance reconnaissance photographs taken on plates as big as 8½ by 6½ with a lens of a focus of six inches. These, when taken at 20,000ft., took in a perfectly enormous area and, although not showing great detail, were extremely useful to the general staff in showing general lines of defence that might be fallen back on.

The book deals very little with any other school of thought but their own, but to myself it recalls with pleasure the kindness of all the French photographic sections in showing us in the most unselfish way their very latest devices and schemes, many of which we adopted, though the interchange was not wholly one-sided.

The book is admirably illustrated, both from the point of diagrams and actual photographs showing camouflage.